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Radioactive Contamination at Federally Owned Facilities

Rogers and Associates Engineering Corp.
Salt Lake City, UT

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Environmental Protection Agency
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RADIOACTIVE CONTAMINATION AT FEDERALLY OWNED FACILITIES

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U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C.

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Federally-controlled facilities that are contaminated with radioactivity are listed and described. Estimates of current levels of contamination are provided and decontamination and decommissioning (D&D) procedures are discussed. All of this information has been gathered from available literature and personal contacts with individuals; no new measurements or site visits were made. Finally, estimates of amounts and activities of low-level and transuranic wastes that can be generated from D&D of federally controlled facilities are provided.

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1. INTRODUCTION

1.1 PURPOSE

The U.S. Environmental Protection Agency (EPA) is developing a series of environmental protection standards governing the disposal of radioactive wastes. Related to these standards is the need for Federal radiation protection guidance on residual radioactivity for use in planning and implementing D&D at nuclear sites, facilities and materials.

In order to properly develop guidance for residual radioactivity, technical assessments are required to characterize the problem, evaluate the risks, examine available D&D methods (including their costs), evaluate occupational risks for these methods, analyze techniques for demonstrating compliance, and review and summarize existing standards and regulations related to D&D. This report is one in a series of reports being prepared for EPA to characterize anticipated waste volumes from decontamination and decommissioning (D&D) of contaminated facilities.

The current series of reports characterizes contaminated sites, facilities, and materials that may eventually require D&D. Information is provided on the types and numbers of contaminated nuclear sites, facilities and materials requiring decommissioning, whether sites are active or inactive, and, if active, the expected remaining operating life. Information is also given on the quantity and concentration of the radioactivity making up the contamination, with special emphasis on long-lived materials. This information includes descriptions of salient chemical characteristics of contaminated items, when available, and estimates of the volumes and nature of radioactive waste which would be produced during decontamination activities.

The EPA has initially categorized the radioactively contaminated sites, facilities and materials into the following seven groupings:

I. Nuclear power reactor sites and facilities (both Light Water Reactors and High Temperature Gas-Cooled Reactors).

II. Nuclear fuel cycle facilities other than reactors (mines, mills conversion and enrichment plants, fuel fabrication facilities, fuel reprocessing and fuel storage facilities, and mixed-oxide fuel fabrication plants).

III. Research, test, university and isotope production reactor sites and facilities.

IV. All Federally-owned sites and facilities, or those for which the government has responsibility, which have radioactive materials or wastes, including U.S. Department of Energy (DOE), national laboratories and sites included in remedial action programs.

V. Radioisotope and radiopharmaceutical manufacturers and suppliers licensed by the U.S. Nuclear Regulatory Commission (NRC) or the states.

VI. Independent research and development laboratories or institutions, including those currently licensed, licensed in the past, and those not licensed. Accelerators are to be included in this group.

VII. All radioactive waste sites, excluding high-level waste repositories and uranium mill tailings respositories (subject to Public Law 95-604, "Uranium Mill Tailings Radiation Control Act of 1978"), regardless of ownership: government, commercial or abandoned.

The EPA has decided that sufficient information is available for Categories I, III and VII and that these facilities will not be characterized at this time.

1.2 SCOPE AND OBJECTIVE OF THIS REPORT

This report covers the Category IV facilities--all Federally-owned sites and facilities, or those for which the Federal Government has responsibility--which have radioactive materials or waste. This category includes the Department of Energy (DOE) national laboratories and all of the sites in the DOE remedial action programs. DOE's remedial action programs include: Formerly Utilized Sites Remedial Action Program (FUSRAP), Uranium Mill Tailings Remedial Action Program (UMTRAP), Grand Junction Remedial Action Program (GJRAP), and the Surplus Facilities Management Program (SFMP).

The Department of Defense (DOD) is also responsible for a large number of sites where there may be radiological contamination and D&D may be needed. These sites are related to nuclear ship propulsion programs, nuclear weapons, research and power reactors, use and storage of depleted uranium munitions and miscellaneous sites. The DOD and DOE programs are often interrelated and sometimes it is difficult to clearly determine responsibility for a specific site.

The Government Services Administration (GSA) is responsible for supervising storage sites for strategic materials stockpiles (GSA77, GSA78). The stockpiles include ores containing natural radioactivity and are stored on DOD and GSA depots and other government leased or owned sites. Other federal agencies responsible for contaminated facilities are the EPA, U.S. Department of Commerce (DOC), and U.S. Department of Interior (DOI), and National Aeronautics and Space Administration (NASA). For the purpose of this report the Tennessee Valley Authority (TVA) is also considered a federal agency.

Sites that only have Nuclear Regulatory Commission (NRC) or state byproduct or special nuclear material licences and contain minimal if any contamination are not included. The old uranium ore burying stations are also excluded from this assessment. The ore buying stations for the former Atomic Energy Commission (AEC), now the DOE, were partially cleaned up. There were also private ore buying stations on Department of Interior land.

The primary emphasis of this report is to identify and characterize the Federally-controlled facilities. Estimates of existing contamination and projections of radioactive wastes from D&D of the facilities are given. This includes:

- Radionuclides making up the contamination including quantities in curies, concentrations in specific activity or contamination in terms of unit volume or area.
- Physical and chemical descriptions of the contamination.
- Estimates of the volumes and characteristics of waste produced by D&D using currently available technology.
- Descriptions of all items contaminated with radionuclides with half-lives greater than 30 years.
- Whether each facility is active or inactive; if active, the expected remaining operating life.
- Lists of all materials which may be suitable for recycle, when available.

1.3 ORGANIZATION OF THE REPORT

Each chapter in this report treats a particular responsible governmental agency. The facilities for each agency are listed in separate chapters.

For several agencies the facilities are further classified according to program, to facilitate compilation of the data.

Chapter 2 describes the methodology used in performing the technical assessments reported in this document, including a brief description of the general approach, assumptions, and categories of contaminated facilities. Subsequent chapters give information on the facilities themselves.

Accelerators and uranium enrichment, reprocessing, conversion and fabrication facilities are not covered in the sections on specific agencies. All government accelerators have been combined into one grouping and are discussed in Chapter 10. The government uranium enrichment, conversion and fabrication facilities are mentioned in the DOE section and listed under the appropriate government laboratories, but their characterization is given in the report on fuel cycle facilities (Be82a). Chapter 3 covers DOE controlled facilities, including the remedial action programs mentioned above. This is by far the largest chapter because the documentation available for DOE facilities is extensive. Chapter 4 discusses DOD facilities and Chapter 5 covers Department of Commerce facilities. Chapters 6, 7, 8 and 9 describe contamination at Department of Interior, General Services Administration, Department of Health and Human Services and Veterans Administration facilities, respectively. Chapter 10 discusses contamination at government controlled accelerators and Chapter 11 covers other federal agencies such as NASA, EPA, TVA and the Department of Agriculture.

Reference facilities for mockup reactors or critical faclities, research reactors, test reactors and production reactors are given in

Appendix A. Information on government fuel reprocessing facilities is given in Appendix B. Appendix C provides a list of accelerators and Appendix D describes characteristics of activation products.

2. METHODOLOGY

This chapter contains a brief description of the methodology used in performing the technical assessment of Federally-controlled sites, facilities and materials.

2.1 APPROACH

The general approach used in this technical assessment is to identify and compile available information on the contaminated sites, and to exercise engineering judgement in extrapolating available information to form estimates of waste types and quantities where no information has been found. Detailed references to available information are provided to facilitate further studies and evaluations.

Some formal D&D activities, such as the DOE remedial action programs (UMTRAP, FUSRAP, etc), have received funding for many years and good estimates of waste characteristics and volumes are available for them from several sources. In those cases the estimates were taken from program summary documents. Cross checks between documents were made. Occasionally reference was made to more basic documents to verify a number from a summary report or to obtain more relevant detail.

In other cases, such as the D&D of reactors and fuel reprocessing facilities, summaries were not available. A reference facility was defined and estimates of wastes were derived for the reference facility. Those estimates were then scaled according to capacity, area, volume, etc, to generate estimates for similar facilities.

For some potential D&D situations, such as nuclear weapons incidents, data sufficient to make estimates of waste volumes is not available. For these, lists of known locations were generated to guide future efforts and to help in understanding the magnitude and diversity of wastes that may some day be generated.

2.2 LITERATURE REVIEW

The scope of this technical assessment is limited to the use of existing information. Therefore a thorough review of available literature provides the basis for information presented in this report. In performing the literature review, the published bibliographies on D&D topics were examined, and data bases were searched. Library facilities at the University of Utah (a DOE Repository Library), the Idaho National Engineering Laboratory (INEL) and Battelle Pacific Northwest Laboratory (BPNL) were used. The data bases searched included

RECON	(DOE's data base of Government reports)
SCISEARCH	
DIALOG	
BRS	(DOE Energy Database)
ORBIT	

Over 50,000 references to radioactive waste are contained in these data bases. The references were narrowed down to manageable numbers by using carefully selected key words. For instance, "Decontamination", "Fuel Reprocessing", and "Waste" together yielded 115 references in the BRS search. The key words, used singly or in various combinations, were: "Radioactive Waste", "Enrichment", "Conversion", "Fuel Storage", "Mixed-Oxide Fuel", "Fuel Reprocessing", "Inventories", "Decontaminate", "Decontamination", "Isotope Separation", "Gaseous Diffusion", "FUSRAP", "Excess Contaminated Facility", "Fuel Fabrication", "Decommission", "Nuclear Waste", "Decommissioning Waste", "Reprocessing Waste", "Accelerators", "Uranium Mines", "Uranium Mills", "Uranium Mill Tailings", "Low-Level Waste" and "Remedial Action Program".

The references obtained from the bibliographies and searches using combinations of the above keywords were then screened to select the most promising titles for further study. Copies of documents were obtained and reviewed to obtain further useful references and the data compiled in this report. The reviewed references also provided names of cognizant individuals who were often contacted for further detailed information.

2.3 OTHER SOURCES OF INFORMATION

As mentioned above, personal communications were made frequently with individuals known by the authors to be involved in work on D&D of radioactive facilities. In addition to providing help in identifying and obtaining useful documents, these contacts often revealed information that is not available in existing reports--either because it has never been published or because values, assumptions, etc have changed since the most recent reports were prepared. Even the most advanced D&D programs experience frequent changes in plans and schedules as a result of new technology, new criteria and budgetary constraints. The use of personal communications has helped to make this assessment as broad and as timely as possible.

2.4 ASSUMPTIONS FOR DECONTAMINATION AND DECOMMISSIONING

For most of the existing contaminated sites, facilities or materials, some information is available concerning the present status. However, there are many facilities now in use for which D&D plans have not been formalized; in some instances, little information is available on radioactive inventories projected to the time of that facility's decommissioning. For some types of facilities there is past experience in D&D, while for others no D&D activities have been attempted. Also, the type of D&D activity to be used at many specific locations has not been decided. For these reasons, there is considerable uncertainty in the estimates presented in this report. However, an effort has been made to present the information on a consistent basis, and to explain the assumptions used in estimating waste volumes and types. This section presents the major assumptions used in the estimates.

2.4.1 Alternatives

There are many possible choices of decontamination methods and degrees of cleanup to be accomplished, as well as many possible options for final site decommissioning. Throughout this report, the term "D&D" is used to mean those activities taken at a contaminated site or facility to prepare it for its projected disposal or release for unrestricted use. Because there has been some misunderstanding in the past about terminology used in the decommissioning field, the NRC has set forth standardized definitions of terms that have been adopted for use in this report. These standard definitions are repeated verbatim here from Ca81:

> "Some confusion and misunderstanding has resulted from the variation of terminology used in the decommissioning field. For example, the words decommission, decontaminate and dismantle have been used interchangeably for the decommissioning alternative consisting of the immediate removal of all radioactive material to permit unrestricted release of the property. The word dismantlement has been used to describe decontamination activities that involve no actual dismantlement. Similarly, the words safe storage, protective storage, lay away, mothball and temporary entombment have been used to name the alternative decommissioning consisting of placing and maintaining property safely in storage as a precursor to final decommissioning.
>
> In the interest of ending the confusion it appears desirable to strictly define decommissioning and the major alternatives for accomplishing it. Furthermore the use of pseudoacronyms for the alternatives avoids words which have several meanings.
>
> Definition of Decommissioning
>
> Decommission means to remove the property safely from service and dispose of the radioactive materials. The level of any residual radioactivity on the property must be low enough to permit unrestricted release of the property.
>
> Definitions of Decommissioning Alternatives
>
> DECON means to immediately remove all radioactive material to permit unrestricted release of the property.
>
> SAFSTOR means to fix and maintain property so that risk to safety is acceptable for a period of storage followed by decontamination and/or decay to an unrestricted level.
>
> ENTOMB means to encase and maintain property in a strong and structurally long-lived material (e.g., concrete) to assure retention until radioactivity decays to an unrestricted level."

The above definitions and alternatives will be used in this report to describe activities. Note that essentially all decommissioning activities at contaminated sites also involve decontamination. Hence, "D&D" will be used throughout this report. Of the three alternatives defined, the one that appears to be most feasible for a given facility will be used in making the estimates that follow.

Many reactors are present at Federal facilities. These have generally been characterized as research, test or production reactors for the purpose of this report. Ko82 concludes that DECON is the preferred method for D&D of test reactors. DECON requires immediate expediture of funds, but allows release of the site for uncontrolled use and saves the expense of continued security and surveillance. There is a fairly narrow line between the alternatives of SAFSTOR and ENTOMB for research and test reactors. It is difficult to envision the ENTOMB alternative being adequately implemented for reactors, given the long half-lives of the activation products imbedded in the vessel and core materials. Therefore, estimates of D&D wastes for reactors are based on the DECON alternative.

2.4.2 Criteria for Levels of Residual Activity

A number of suggested criteria for allowable levels of radioactivity after D&D exist. They include the Surgeon General's Criteria used in the Grand Junction, Colorado Remedial Action Program (PHS70), "Interim Cleanup Standards for Inactive Uranium Processing Sites" (EPA80), Draft American National Standard "Control of Radioactive Surface Contamination on Materials, Equipment and Facilities to be Released for Uncontrolled Use"

(ANSI78), "Proposed Federal Radiation Protection Guidance For Persons Exposed to Transuranic Elements in the Environment" (EPA77) and "Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source or Special Nuclear Material" (NRC75). Reference Sh79 contains an analysis of current decommissioning regulations. The NRC has also recently published a draft generic environmental impact statement on decommissiong of nuclear facilities (NRC81). Guidance on uranium mill tailings is provided in NRC80. An additional summary of current D&D guidance is given in Volume 2 of Ba76. Most of the criteria and standards are promulgated for guidance only and major remedial action programs such as UMTRAP are awaiting final standards before proceeding in earnest.

The criteria and standards can cover a wide range of nuclides. They are usually based on specific assumptions about future uses of the decontaminated buildings, land, etc and are related to assumed acceptable levels of exposure to individuals. The two most commonly used cleanup standards are the EPA's recommendations of 0.2 microcuries per square meter of transuranics in soil (surface contamination to a depth of one centimeter) (EPA77) and 5 pCi/g of radium-226 in the top 5 cm of soil (EPA80 and EPA80a). The first figure can be translated into approximately 15 pCi/g of soil.

While cleanup criteria may play a role in estimating the volumes of waste from D&D and concentrations of nuclides in that waste, information about existing radioactivity at facilities requiring cleanup is usually not available in sufficient detail to observe the effects of different standards. For some programs, such as UMTRAP, cleanup standards have reached a stage that allows estimates of wastes from D&D to be based on anticipated values. Those estimates are incorporated in this assessment whenever possible, but the majority of the estimates of waste volumes and concentrations contained here are based on engineering judgements that are not tied to specific cleanup criteria.

3. DOE-CONTROLLED FACILITIES

3.1 INTRODUCTION

The U.S. Department of Energy (DOE) has responsibility for most of the government controlled contaminated sites, facilities and materials in this country. There are DOE facilities present in almost every state. Facilities range from small, slightly contaminated laboratory type rooms to large, complex, highly contaminated processing plants as well as surrounding contaminated lands. Besides facilities that are government owned, DOE has responsibility for some sites that were formerly used in government operations or for the benefit of the government. This chapter presents a summary and analysis of the DOE-controlled facilities.

DOE-controlled facilities are and have been used in essentially all phases of the nuclear fuel cycle: in nuclear weapons research, development and production, in medical and biological research, in industrial applications and development, and other productive uses of radioactive materials. Some facilities have not been used for many years, others have been used for purposes other than those for which they were initially designed. Several facilities are approaching the end of their productive lifetimes, while many are still active with no projected end of their usefullness.

DOE-controlled facilities have evolved and been inherited from predecessor agencies and programs, such as the Manhattan Engineer District (MED), the Atomic Energy Commission (AEC) and the Energy Research and Development Administration (ERDA). Over time, programs and objectives change, resulting in changed facility requirements. Some research reactors, for instance, have undergone several modifications to suit changing needs, yet remain basically the same facility, while others have become obsolete and are no longer in use.

Radioactive waste from D&D of DOE-controlled facilities will be as diverse as the different types of facilities from which it is generated. The types and levels of radioactive contaminants, physical and chemical forms, and handling considerations for the wastes from D&D will depend on the uses to which the facilities have been put, the current status of the facilities, and when D&D takes place. For DOE-controlled facilities, a distinction is often made between wastes generated in national defense activities, termed defense waste, and wastes from other activities, termed commercial waste. At the present time, for instance, DOE is proceeding with plans for a "defense transuranic waste" repository known as the Waste Isolation Pilot Plant (WIPP) (DOE80e). WIPP will not accept commercial TRU waste, even if it has similar characteristics as the defense TRU waste. Similarly, there may be future distinctions concerning the fate of D&D wastes, depending on the former use of a contaminated facility. However, for the purposes of this report, no further distinction of this type will be attempted, other than a general identification of the responsible government agency or program.

3.2 FACILITY CLASSES

The major DOE facilities include the National Laboratories, those under the Formerly Utilized Sites Remedial Action Program (FUSRAP), those associated with the Uranium Mill Tailings Remedial Action Program (UMTRAP), the Grand Junction Remedial Action Program (GJRAP), the Surplus Facilities Management Program (SFMP), and facilities associated with specific research and development programs.

Several classes of DOE facilities are discussed in other reports or other chapters of this report. Uranium enrichment facilities are covered in Be82a. Active fuel conversion and fabrication facilities are also covered in Be82a; however the surplus facilities are included in this section. DOE and other government accelerators are considered in Chapter 10 of this report.

3.3 DOE PROGRAMS FOR D&D

DOE has several ongoing programs that directly involve the D&D of DOE-controlled facilities or sites contaminated by activities of DOE and its predecessors. These programs, categorized as Remedial Action Programs, are:

- The Uranium Mill Tailings Remedial Action Program (UMTRAP), is the implementation of Public Law 95-604, PL78. The program includes remedial action on 24 inactive uranium mill tailings sites and associated properties. This program is concerned with a larger volume of waste material than the other remedial action programs; about 29 million metric tons of tailings and contaminated soil beneath them and 5 million metric tons of other wastes from the 24 sites.

- The Formerly Utilized Sites Remedial Action Program (FUSRAP) encompasses sites used by the former Manhattan District and AEC for work with nuclear materials. The work was primarily oriented to the development of nuclear weapons. Site sizes vary considerably from a small area in a building (e.g., a laboratory) to a large outdoor area such as a former storage site for radioactive ores. Originally over 100 sites were evaluated, but efforts currently focus on 35. The estimated volume of waste, consisting primarily of contaminated soil and building rubble, is about 470,000 m^3.

- The Surplus Facilities Management Program (SFMP) oversees remedial action on approximately 500 surplus DOE facilities that are surplus, or will become surplus in the near future. This program, which was initiated in 1980, is scheduled to complete the necessary D&D for the present list of facilities by 2000. The objective is to decontaminate these facilities sufficiently to permit other productive uses. Currently operating facilities may eventually become candidates for the SFMP program. Waste will consist of contaminated soil, building rubble, metal, and other miscellaneous materials. Most of the waste will be low level, but some TRU waste will be generated.
- The Grand Junction Remedial Action Project (GJRAP) has been under way since 1973 to oversee the rehabilitation of structures that utilized uranium mill tailings in some phase of their construction.

The other five categories in the DOE listing refer to currently active facilities. They are:

- Diversified Laboratories These are major facilities which have diversified programs. There are nine major national laboratories in this category.
- Nuclear Materials Production facilities, devoted to manufacturing nuclear fuels and targets.
- Weapons Production and Testing Facilities, concerned with nuclear weapons, from the design and testing phases to the full production phase. Six complexes are included in this category.
- Physical Research facilities devoted to basic research at universities.
- Miscellaneous Facilities, including small laboratories for fusion and nuclear safeguards work.

A discussion of each of the nine categories of DOE controlled facilities follows.

3.3.1 Uranium Mill Tailings Remedial Action Program (UMTRAP)

The UMTRAP is devoted to D&D of currently inactive uranium mill tailings piles and associated contaminated properties. The following description of UMTRAP responsibilities is taken from information given by DOE80 and DOE81.

Public Law 95-604 (PL78), the "Uranium Mill Tailings Radiation Control Act of 1978," authorized the DOE to organize the Uranium Mill Tailings Remedial Action Program (UMTRAP). Title I of the Act authorizes the DOE, in cooperation with the states and Indian tribes within whose boundaries the inactive deposits of uranium mill tailings lie, and with persons who own or control these inactive uranium mill tailings sites, to provide a program of assessment and remedial action at such sites. The purpose of the remedial action is to stabilize and control these tailings in a safe and environmentally sound manner and to minimize or eliminate the radiation health hazards to the public. The program must consider, where appropriate, the reprocessing of tailings to extract residual uranium and other valuable minerals.

As defined in Public Law 95-604, the term "processing site" means any site, including the mill, containing residual radioactive materials at which all or substantially all of the uranium was produced for sale to the Federal Government and which otherwise satisfies the criteria established in Section 101(6)(A) of the Act. The term "vicinity property" means any other real property or improvement theron which is in the vicinity of such a site and which is determined by the DOE, in consultation with the Nuclear

Regulatory Commission (NRC), to be contaminated with radioactive materials from such a site, as defined in Section 101(6)(B) of the Act.

Much of the uranium ore mined within the United States from the early 1940s through 1970 was processed for the Manhattan Engineering District (MED) and the Atomic Energy Commission (AEC) by private companies. When processing operations ceased for the government and a mill became inactive, large quantities of uranium mill tailings remained.

In the early years, little was known about the effects of the radioactivity on the public and there was little concern about the residual natural radioactivity left in the mill tailings. However, in the course of time, research on the effects of low-level radiation progressed and radiological criteria became more stringent. In 1972 Congress passed Public Law 92-314 (PL72) to provide authority and funds for a cooperative state-federal program to perform remedial actions on structures in Grand Juction, Colorado, where mill tailings had been used for construction. (See Section 3.3.4 for a description of the GJRAP).

A second program was initiated in 1972 to perform an initial evaluation of the primary inactive uranium mill tailings sites that had provided uranium exclusively to the federal government to determine their radiological status and potential health effects on the public. The AEC and EPA subsequently proposed that a comprehensive study be performed of all formerly active uranium mill tailings sites. It was concluded that some form of remedial action was required at most of these sites. In order to alleviate potential public health hazards, in 1978 Public Law 95-604 (PL78) was enacted.

In enacting this legislation, Congress determined that the Federal Government should perform remedial actions at inactive mill tailings sites located on private property because the then-existing NRC regulatory authorities were inadequate to require private remedial action on these properties. Title I of the act stipulates that DOE will meet radiation standards to be promulgated by EPA (under Title II) for this purpose and that the remedial action is to be carried out within the 7-year period following the promulgation of such standards by EPA. Further, DOE will finance 90 percent of the remedial action costs, and the affected states will be required to pay the remaining costs from non-federal funds. An exception to this requirement is those sites on Indian tribal lands, where 100 percent of the costs for remedial action will be borne by the federal government.

Title II of Public Law 95-604 amended the Atomic Energy Act of 1954 to include residual radioactive materials (i.e., uranium and thorium mill tailings) in the definition of byproduct material. Title II also amends the Act to give EPA authority to issue standards for protection of the public health, safety, and the environment from radiological and nonradiological hazards associated with residual radioacitve materials. These standards (present drafts, EPA80, EPA81) will be the basis for DOE implementation of UMTRAP.

The UMTRAP is being implemented in the DOE by the Office of the Assistant Secretary for Nuclear Energy (ASNE) and by the Office of the Assistant Secretary for Environmental Protection, Safety and Emergency Preparedness (ASEPSEP). Support for the remedial action program involves other major offices within DOE, including the Office of General Counsel, the Office of Administration and the Office of Procurement and Contract Management. The DOE is required to consult with NRC on the designation of processing sites and vicinity properties.

Title II of the Act also gives the NRC statutory authority to directly license and promulgate regulations over the tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source-material content.

3.3.1.1 Status

Public Law 95-604 named 22 inactive processing sites--21 in the western U.S. and one at Canonsburg, Pennsylvania. Responses to a Federal Register notice, press releases and communications with the Governors of uranium-producing states regarding designating and establishing remedial action priorities at these sites resulted in identifying and designating three additional sites requiring remedial action. The latter are located in the vicinities of Bowman and Belfield, North Dakota, and Baggs, Wyoming. Subsequently, responsibility for D&D of the Baggs site was removed from UMTRAP because the site is owned by the Bureau of Land Management.

The 24 processing sites shown in Figure 3-1 are designated with the site cleanup priorities shown in Table 3-1 (the two sites each at Rifle and Slick Rock, Colorado are counted separately). There are nine high priority sites, with early emphasis placed upon four because the radiation health risks are greatest at those locations. These four sites are:

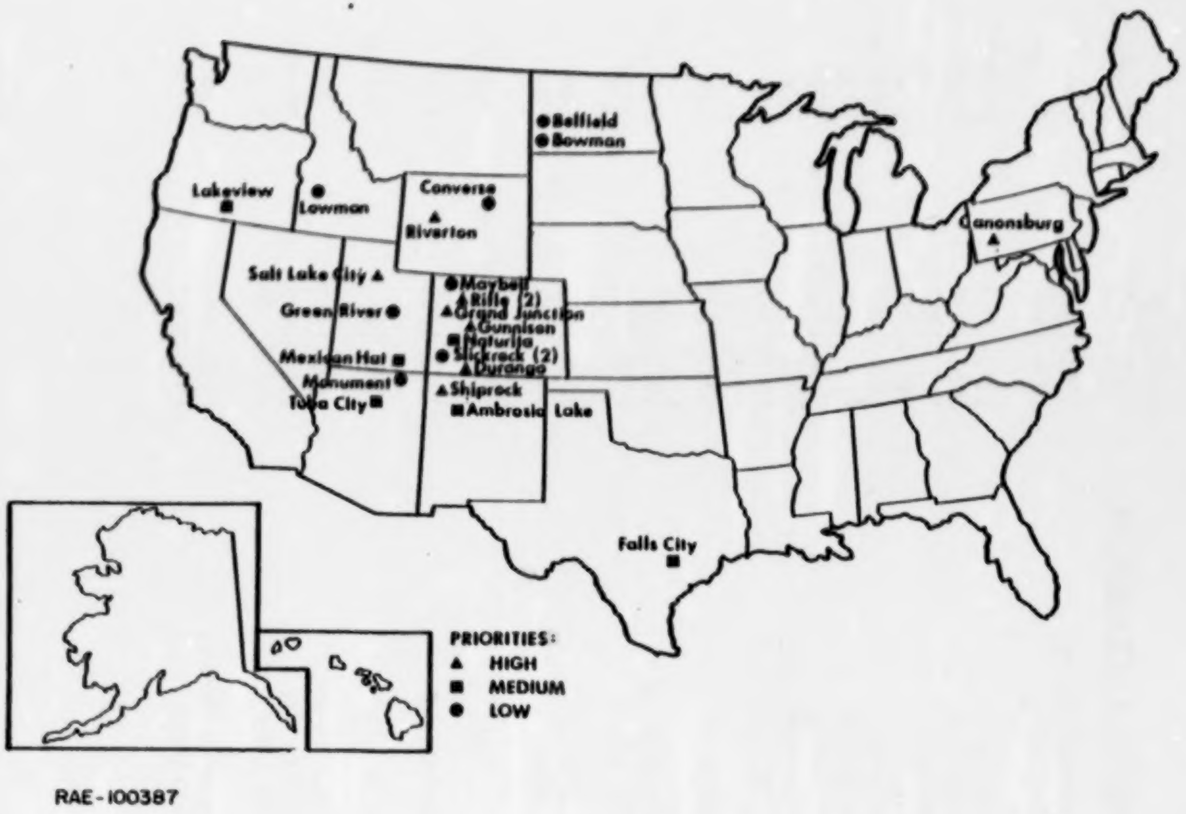
Belfield
Bowman
Lakeview
Lowman
Converse
Riverton
Canonsburg
Salt Lake City
Green River
Maybell
Rifle (2)
Grand Junction
Gunnison
Naturita
Slickrock (2)
Durango
Mexican Hat
Monument
Tuba City
Shiprock
Ambrosia Lake
Falls City
PRIORITIES:
▲ HIGH
■ MEDIUM
● LOW
RAE-100387

FIGURE 3-1. LOCATIONS OF UMTRAP SITES

TABLE 3-1

UMTRAP SITES AND REMEDIAL ACTION PRIORITIES
Source: DOE81

STATE	PROCESSING SITE/LOCATION	PERIOD OF OPERATION	PRIORITY
Arizona	Monument Valley	1955-1967	Low
	Tuba City	1956-1966	Medium
Colorado	Durango	1943-1963	High
	Grand Junction	1951-1970	High
	Gunnison	1958-1962	High
	Maybell	1957-1964	Low
	Naturita	1939-1963	Medium
	New Rifle	1958-1972	High
	Old Rifle	1924-1958	High
	Slick Rock (NC)	1931-1943	Low
	Slick Rock (UC)	1957-1961	Low
Idaho	Lowman	1955-1960	Low
New Mexico	Ambrosia Lake	1958-1963	Medium
	Shiprock	1954-1968	High
North Dakota	Belfield	1964-1966	Low
	Bowman	1964-1967	Low
Oregon	Lakeview	1958-1961	Medium
Pennsylvania	Canonsburgh	1942-1957	High
Texas	Falls City	1961-1973	Medium
Utah	Green River	1958-1961	Low
	Mexican Hat	1957-1965	Medium
	Salt Lake City	1951-1968	High
Wyoming	Converse County	1962-1965	Low
	Riverton	1958-1963	High

- Canonsburg, Pennsylvania
- Salt Lake City, Utah
- Durango, Colorado
- Shiprock, New Mexico

The remaining high priority sites where remedial action will begin as soon as feasible are

- Gunnison, Colorado
- Grand Junction, Colorado
- Rifle, Colorado (2 sites)
- Riverton, Wyoming

Several other potential sites were considered but not included in UMTRAP. They include

- The Anaconda site near Bluewater, New Mexico, and the Homestake-New Mexico Partners site near Milan, New Mexico. These sites are active but have inactive uranium mill tailings piles created solely by federal contract work. It was concluded that the NRC and the State of New Mexico have sufficient authority to require the current owners to take necessary action at these sites to protect the public health and safety and the environment.
- Edgemont, South Dakota - This site is owned by the Tennessee Valley Authority, a federal agency, and is also under active license with the NRC. It was therefore excluded under Section 101(6)A of PL78.
- Monticello, Utah - The site is owned by the DOE and was excluded for the same reason as the Edgemont site.
- Ray Point, Texas - This site was excluded because most of the uranium concentrate produced was not sold to the federal government.

- Hite, Utah - This site is presently under the waters of Lake Powell, and is covered with silt.
- Active Mill Sites With Comingled Tailings Sites - Many uranium mill sites that are still in operation have tailings in their active tailings piles resulting from federal contract work. Because they are under active license with the NRC, they are excluded from UMTRAP.

Off-Site Properties - Under the provisions of Section 102(e)(2) of PL78 the Environmental and Safety Engineering Division of the Office of the Assistant Secretary for Environmental Protection, Safety and Emergency Preparedness is developing radiological assessment data on properties outside the boundaries of the 24 designated processing sites. This radiological characterization program is being conducted on a site-by-site basis and incorporates the results of gamma radiation screening surveys of properties near inactive uranium mill tailings sites that were conducted in 1972 by the Environmental Protection Agency. The assessment is to determine whether residual radioactive material from the 24 primary sites is present at the off-site properties. Some of the findings of those early surveys are summarized in Table 3-2. The numbers of tailings-related anomalies suggests that the volumes of material to be disposed of under UMTRAP may increase significantly over the amount of the tailings on the designated sites.

Since 1972, some state agencies, such as those in Colorado and Utah, have continued to collect radiological assessment data to further identify the presence of residual radioactive materials outside the boundaries of processing sites under their jurisdiction. In some instances, the DOE has determined that more extensive radiological assessments are required to

TABLE 3-2

INITIAL EPA GAMMA SCREENING OF OFF-SITE PROPERTIES[a]

Source: DOE80a, EPA80a

Site Location	Number of Anomalies	Cause of Anomaly			
		Confirmed Tailings	Other Radioactive Source of Ore	Natural Radioactivity	Unknown
Monument Valley, AZ[b]	19	15	4	0	0
Tuba City, AZ	17	7	0	3	7
Durango, CO	354	118	67	67	102
Grand Junction, CO	14,000	Investigated and Being Cleaned Up Under GJRAP (Section 3.3.4)			
Gunnison, CO	47	3	9	28	7
Maybell, CO		No Properties in Vicinity of Site			
Naturita, CO	33	10	20	1	2
Rifle, CO (2 Sites)	810	168	27	1	614
Slick Rock, CO (2 Sites)	9	3	6	0	0
Lowman, ID	12	9	0	3	0
Ambrosia Lake, NM	101	7	50	25	19
Shiprock, NM	9	8	1	0	0
Belfield, ND		Not Surveyed by EPA			
Bowman, ND		Not Surveyed by EPA			
Lakeview, OR	18	0	2	10	6
Canonsburg, PA		Not Surveyed by EPA			

TABLE 3-2 (CONT)

		Cause of Anomaly			
Site Location	Number of Anomalies	Confirmed Tailings	Other Radioactive Source of Ore	Natural Radioactivity	Unknown
Falls City, TX	5	2	0	3	0
Green River, UT	23	1	14	1	7
Mexican Hat, UT[c]	5	0	5	0	0
Salt Lake City, UT[d]	230	70	15	76	69
Baggs, WY			Not Surveyed by EPA		
Converse County, WY	28	13	10	3	2
Riverton, WY	86	15	15	33	23

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[a] Many areas surveyed (EPA80a) are not included in this summary because they did not appear to contain tailings from the UMTRAP sites (DOE80a).

[b] Cane Valley was not included in original survey, but was surveyed in 1975 (EPA80a).

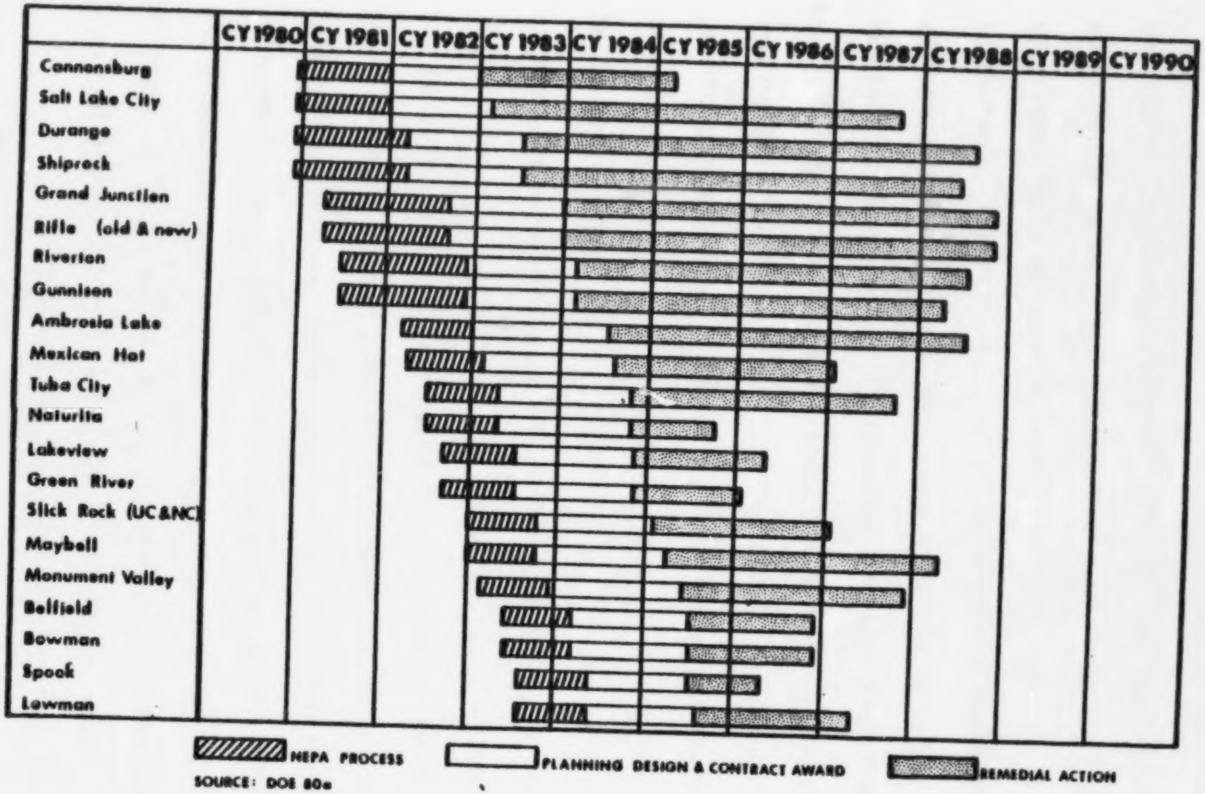
[c] Does not include mill site.

[d] Salt Lake City was not completely surveyed.

thoroughly define the extent of migration or removal of residual radioactive materials to vicinity properties.

The Assistant DOE Secretary for Environmental Protection, Safety and Emergency Preparedness is authorized to designate for remedial action those properties in the vicinity of the designated processing sites containing residual radioactive materials from such sites. The initial ground-based gamma radiation survey only covered a small area around the Salt Lake City site. Since the first aerial survey indicated radiation anomalies that had not been detected by the initial ground-based survey, a second aerial survey was conducted that covered an additional 158 square miles. Preliminary results indicated about 10 locations in the new area that might contain tailings. Aerial radiological surveys have been conducted by DOE at all the high priority sites shown in Table 3-1 and in the vicinities of Canonsburg, Salt Lake City, Mexican Hat and Monument Valley. An extensive radon monitoring program was initiated at Canonsburg to determine the effect of current radon releases from uranium mill tailings piles on the radon concentrations in the surrounding environment, monitor changes in the radon emissions around the site during remedial actions and verify that remedial actions taken at a particular site are effective. Currently, there are a total of 50 radon monitors installed around the Canonsburg site. The proposed sequence of remedial action for 23 sites is shown in Figure 3-2. The status of the site at Falls City is uncertain; consequently it has been omitted from the preliminary schedules.

The status of the UMTRAP sites in 1980 is summarized in Table 3-3,



SOURCE: DOE 80a

RAE-100388

FIGURE 3-2. REMEDIAL ACTION PROJECT MASTER SCHEDULE

TABLE 3-3

SUMMARY OF SITE CONDITIONS, 1980
(Source: Ref. FBDU)

State	Processing Site/ Location	Condition of Tailings(1)	Conditions of Structures On Site(2)	Mill Housing(3)	Property Close to River or Stream	Houses or Industry Within 0.5 Mi	Evidence of Wind or Water Erosion	Tailings Removed For Private Use
Arizona	Monument Valley	U	R	N	No	Yes	Yes	Yes
	Tuba City	U	PR-UO	E-P	No	Yes	Yes	No
Colorado	Durango	P	PR-UO	N	Yes	Yes	Yes	Yes
	Grand Junction	S	PR-O	N	Yes	Yes	Yes	Yes
	Gunnison	S	B-O	N	Yes	Yes	No	No
	Maybell	S	R	N	No	No	Yes	No
	Naturita	RMS	PR-O	N	Yes	Yes	Yes	No
	New Rifle	P	M-O	N	Yes	Yes	Yes	No
	Old Rifle	S	PR-UO	N	Yes	Yes	No	Yes
	Slick Rock (NC)	S	R	N	Yes	Yes	Yes	No
	Slick Rock (UC)	S	R	E-P	Yes	Yes	No	No
Idaho	Lowman	U	R	N	Yes	Yes	Yes	Yes
New Mexico	Ambrosia Lake	U	PR-O	N	No	No	Yes	No
	Shiprock	S	PR-O	N	Yes	Yes	No	Yes
North Dakota	Belfield	R	PR-O	N	No	Yes	No	No
	Bowman	R	R	N	No	No	No	No
Oregon	Lakeview	S	B-O	N	No	Yes	Yes	No
Pennsylvania	Canonsburg	P	B-O	N	Yes	Yes	No	Yes
Texas	Falls City	P	B-O	N	No	No	Yes	No
Utah	Green River	S	B-O	N	Yes	Yes	Yes	No
	Mexican Hat	U	PR-UO	E-O	No	Yes	Yes	No
	Salt Lake City	U	R	N	Yes	Yes	Yes	Yes
Wyoming	Converse County	U	R	N	No	No	No	No
	Riverton	S	PR-O	N	No	Yes	No	No

(1) S - Stabilized but requires improvement
P - Partially stabilized
U - Unstabilized
RMS - Reprocessed, moved and stabilized - contamination remaining
R - Removed - contamination remaining

(2) M - Mill intact
B - Building(s) intact
R - Mill and/or buildings removed
PR - Mill and/or buildings partially removed
O - Occupied or used
UO - Unoccupied or unused

(3) N - None
E - Existing
O - Occupied
P - Partially occupied

taken from FBDU.*

3.3.1.2 Representative UMTRAP Facility

The UMTRAP facility at Mexican Hat, Utah is described here as representative of UMTRAP sites. The following description is taken largely from FBD81.

The Mexican Hat site is a 555-acre tract now called "Halchita" on the Navajo Indian Reservation about 1.5 mi southwest of Mexican Hat, Utah. The mill and tailings areas are situated on ground sloping north toward the San Juan River. Tailings ponds were formed by use of natural slopes on the south and west sides of the pond and earth dikes on the north and east sides. Tailings were deposited to depths of up to 40 ft.

The surrounding country is arid and desertlike with low, rolling hills and steep washes where basins have been formed by drainage tributaries of the San Juan River. Vegetation is sparse. The elevation of the site is about 4,250 ft above sea level.

The mill was constructed and operated from 1957 to 1965. Texas-Zinc Minerals Corporation built and operated the plant until July 1963 when it was sold to Atlas Corporation, which operated it until shutdown. Before and during this period the site was under ownership of the Navajo Tribe. When the Atlas lease expired in 1970, control of the site reverted to the Navajo Nation. The Utah Navajo Development Corporation now has rights to use of the site.

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* Reference FBDU refers to a collection of engineering assessments of inactive uranium mill tailings sites produced by Ford, Bacon and Davis Utah over the period 1976 to 1981 and available through the UMTRAP Office, DOE Albuquerque Operations Office, Albuquerque, New Mexico, 87115.

The mill processed 2.2 million dry tons of ore with an average grade of 0.28% U_3O_8 and produced 5,700 tons of U_3O_8 in concentrate. In addition to the uranium operation, a sulfuric acid plant was in operation at the site and continued to operate until 1970.

There are two adjacent tailings piles comprising 68 acres. These are referred to as the upper (25 acres) pile and lower pile. The piles have not been stabilized and are subject to wind and water erosion. Erosion has carried the tailings down the washes toward the San Juan River. The site is not fenced. Wind has transported tailings more than one half mile from the piles in the northeast direction.

Seven of the buildings and the concrete pad of the mill building remain intact, but all of the milling equipment has been removed. An elementary school with about 200 students and 27 faculty members is located about 0.3 mi southwest of the mill site. The housing area (Halchita) is about 0.6 mi southwest of the mill site and has an estimated present population of 230 persons.

The tailings are situated in a wash and therefore block the normal surface drainage existing previously. Diversion channels have been cut around the south and east sides of the tailings to route surface runoff around the tailings. Several washes meet northeast of the lower tailings pile and lead to the San Juan River. Windblown tailings in these washes could be carried into the river during rainstorms. Surface water is found at two locations near the site; one is a sewage pond near the mill building and the other is a small pond in the wash northeast of the tailings.

The deep groundwater of the area around Mexican Hat and the thick

Halgaito siltstone beneath the tailings create conditions under which groundwater contamination by the tailings is highly unlikely.

The average annual precipitation at Bluff, Utah, 27 mi to the northeast of Mexican Hat, is about 7.5 in. Precipitation at Mexican Hat is similar in character. Strong winds are common throughout the Colorado Plateau. Dune patterns and windblown tailings indicate strong southwesterly winds in the vicinity of Mexican Hat.

Measurements of radon flux from the tailings made in 1976 ranged from 16 to 1,600 pCi/m^2sec on the tailings piles. Twenty-four hour average radon measurements performed in 1976 0.5 and 0.8 mi from the Mexican Hat tailings site gave background radon concentrations of 0.6 pCi/l. Other samples have indicated backgrounds of 0.3 to 0.4 pCi/l.

Background values of gamma radiation beyond 0.4 mi from the Mexican Hat site averaged 9 μR/hr. The range of values was from 6 to 12 μR/hr. Above the surface of the exposed tailings gamma readings ranged from 200 to 1,600 μR/hr.

Four surface water samples taken in the vicinity of the site were analyzed for Ra-226. Concentrations ranged from 0.52 to 2.46 pCi/l. They were less than the limits of the EPA Interim Primary Drinking Water Regulations of 5 pCi/l for Ra-226 and Ra-228. A fifth sample from a stagnant pond northeast of the site had 16 pCi/l of Ra-226. One of the four samples mentioned above was collected downstream from this stagnant pond, and the Ra-226 concentration was only 0.89 pCi/l.

The amount of Ra-226 activity in the tailings and the extent of past leaching of radium from the tailings into the soil have been determined by drilling bore holes through the tailings and into the soil below. The siltstone beneath both tailings piles limited the contamination to less than 3 ft below the soil-tailings interface. A few locations in the former ore storage area had radium concentrations up to 1,000 pCi/g at the surface. Concentration decreased to background levels at a depth of 2 ft.

About 85 percent of the total radioactivity originally in the uranium ore remained in the tailings after removal of the uranium. The principal potential environmental radiological impact and associated health effects arise from the Th-230, Ra-226, Rn-222 and Rn-222 daughters contained in the uranium tailings. Although these radionuclides occur in nature, their concentrations in tailings material are several orders of magnitude greater than their average concentrations in the earth's crust. Because of the chemical treatments these radionuclides have experienced, it appears that Ra-226 is more soluble and, therefore, more mobile than in its natural state.

3.3.1.3 Existing Contamination

A considerable amount of investigation of contamination at the UMTRAP sites has been performed (FBDU). Information generated is summarized in DOE80c and EPA80. Tables 3-4 and 3-5 list key characteristics of contamination at the existing UMTRAP sites. Most of the radioactive materials at the UMTRAP sites are mill tailings--unconsolidated sands and slimes--which are usually handled with earth-moving equipment. Therefore, their volume and weight are of interest in considering disposal options and costs. Furthermore, most of the tailings have been in the same location

TABLE 3-4

ESTIMATES OF TAILINGS AT UMTRAP SITES

State	Processing Site/Location	Area of Tailings (ha) (DOE80c)	Tailings Volume ($10^3 m^3$) (DOE80c)*	Tailings Weight (10^3MT) (EPA80)*	Average Ra-226 (pCi/g) (EPA80)
Arizona	Monument Valley	12	620	1,100	50
	Tuba City	8.9	450	700	920
Colorado	Durango	8.5	870	1,400	700
	Grand Junction	24	1,070	1,700	780
	Gunnison	16	300	500	420
	Maybell	32	1,500	2,400	270
	Naturita	9.3	350**	600	800
	New Rifle	13	1,500	2,500	870
	Old Rifle	5.3	200	320	1,100
	Slick Rock (North Continent)	2.4	22	33	780
	Slick Rock (Union Carbide)	7.7	210	320	690
Idaho	Lowman	2.0	51	70	530
New Mexico	Ambrosia Lake	43	1,500	2,400	640
	Shiprock	29	960	1,500	700
North Dakota	Belfield	9.7	Tailings Removed		
	Bowman	8.5	Tailings Removed		
Oregon	Lakeview	12	73	120	420
Pennsylvania	Canonsburg	7.7	100	170	
Texas	Falls City	59	1,400	2,300	450
Utah	Green River	3.6	76	110	810
	Mexican Hat	28	1,300	2,000	780
	Salt Lake City	45	1,100	1,700	900
Wyoming	Converse County	2.0	110	170	340
	Riverton	29	540	820	560

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* Verified and adjusted by reference to the FBDU documents.
** Estimated from the tailings weight using 1.7 MT/m^3.

TABLE 3-5

ESTIMATES OF MATERIALS OTHER THAN TAILINGS
(Source: FBDU unless otherwise noted)

State	Processing Site/Location	Bulk Materials		Rubble		Off-Site Contaminated Soils		Ore		Unspecified**
		(10^3 MT)	($10^3 m^3$)	(10^3 MT)	($10^3 m^3$)	(10^3 MT)	($10^3 m^3$)	(10^3 MT)	($10^3 m^3$)	(10^3 MT)
Arizona	Monument Valley	--	--	--	--	--	--	--	--	--
	Tuba City	89	56	--	--	--	--	--	--	--
Colorado	Durango	460	270	74	35	16	10	--	--	--
	Grand Junction	1,000*	670*	140	92	--	--	--	--	--
	Gunnison	80	37	--	--	--	--	--	--	--
	Maybell	91	54	--	--	--	--	--	--	--
	Naturita	310*	200*	7	4	--	--	--	--	--
	New Rifle	1	1	--	--	--	--	--	--	--
	Old Rifle	9	5	--	--	--	--	--	--	--
	Slick Rock (North Continent)	6	4	--	--	--	--	--	--	--
	Slick Rock (Union Carbide)	18	12	--	--	--	--	--	--	--
Idaho	Lowman	--	--	--	--	--	--	5	--	--
New Mexico	Ambrosia Lake	--	--	--	--	--	--	--	--	--
	Shiprock	1,400*	820*	41	23	1	1	--	--	--
North Dakota	Belfield	--	--	--	--	--	--	--	--	46
	Bowman	--	--	--	--	--	--	--	--	42
Oregon	Lakeview	--	--	--	--	--	--	--	--	95
Pennsylvania	Canonsburg	63***	37	14	6	--	--	--	--	14
Texas	Falls City	--	--	--	--	--	--	--	--	550
Utah	Green River	11	7	--	--	--	--	--	--	--
	Mexican Hat	20	15	--	--	--	--	--	--	--
	Salt Lake City	970*	600*	110	60	300	190	--	--	--
Wyoming	Converse County	--	--	--	--	--	--	--	--	--
	Riverton	730*	580*	--	--	82	51	--	--	--

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* Includes soil from under tailings.
** Source is DOE80c.
*** Weight calculated from the volume using 1.7 MT/m^3.

for several decades, allowing some radionuclides to seep into the soils below them; removal of the tailings will involve removing some of the underlying soil to get levels of residual contamination down to standards. The key nuclide of interest in cleaning up the mill tailings is Ra-226. Approximately 90 percent or more of the uranium (or, in some cases thorium) was removed in the milling process, so specific activities of uranium daughters-- primarily thorium and radium--are an order of magnitude higher than the specific activity of uranium, assuming equilibrium in the ore. Radium-226 is of interest because its daughter radon-222 diffuses from the tailings and its daughters can be particularly dangerous to the health of persons living nearby. Also, radium is the most toxic of the uranium daughters when ingested. While the concentration of Ra-226 in the mill tailings at a particular site can vary spatially by an order of magnitude, the average concentration shown in Table 3-4 is a good measure of the average toxicity of the tailings.

In addition to the tailings, most UMTRAP sites contain some structures, machinery, soil, etc. that were connected with the mill which are contaminated and must be disposed or decontaminated. The materials range from a high of about 90 percent of the tailings weight at Shiprock, New Mexico, to less than one percent at other sites. The FBDU references provide details of the materials other than tailings that will probably have to be considered in D&D of UMTRAP sites. Table 3-5 was prepared from these documents by aggregating various materials into four categories:

- Bulk Materials - Contaminated soils, dikes, cover materials, riprap, mulch, etc. on the UMTRAP site that can be generally handled using earthmoving equipment.

- Rubble - Concrete foundations and other material described as rubble that may have a higher density than soil, require different handling and may be considered a different waste form for disposal purposes.
- Off-Site Contaminated Soils - While similar to on-site soils once collected, off-site contamination (generally wind-blown tailings less than a few inches thick) will require different and generally more costly procedures to gather.
- Ore - Some sites have stockpiles of unprocessed ores.

Note that some of the estimates of bulk materials include contaminated soils under the tailings and others do not.

A fifth category, unspecified, is included in Table 3-5. This information was gathered from DOE80c. No waste volume information was available in that source. For the Lakeview, Oregon site, DOE80c indicates 105,000 MT of other wastes to be treated but the buildings, etc. at that site have already been decontaminated. Therefore no number is given in Table 3-5 for Lakeview.

3.3.1.4 D&D Procedures

Procedures for reducing radiological risks at UMTRAP sites to acceptable levels divide into two major categories:

- Stabilization In Place - Leaving the tailings in their present location and providing stabilization adequate to prevent unacceptable doses due to radon and airborne particulate releases and due to erosion or migration into ground and surface waters.
- Removal and Shallow Burial - Removing the tailings and other waste to a suitable disposal site where it can be satisfactorily stabilized and the objectives stated above for in-place stabilization realized.

Both alternatives lead to something like an ENTOMB condition, in the terminology defined in Section 2.4.1. However, the half-lives of the nuclides of interest are so long that the time required to decay to an unrestricted level is beyond the experience of human society. The latter action listed above can also be construed to be a DECON activity for the site where the tailings presently reside.

Generally in-place stabilization will be much less expensive, but removal and shallow burial is also being considered for some UMTRAP sites. For example, at Durango the tailings are at the side of a river and may be subject to massive erosion or slumping during extremely adverse weather conditions. In the case of UMTRAP wastes, the long period over which they will maintain their current level of toxicity will be a significant factor in determining the adequacy of on-site stabilization.

Aside from the disposition of tailings, some sites have large quantities of other materials (see Table 3-5). The majority of these are soil, rubble, etc. which have lower average radium concentrations than the tailings at the corresponding site because their contamination occurred through surface contact with the ore or seepage of ore or tailings. If the tailings are removed the other wastes will almost certainly be removed also. If the tailings are stabilized in place the other wastes may be placed in or on top of the tailings and also left on the site. In fact, some of the wastes listed in Table 3-5 are soil presently used as covers over the tailings and will become part of the stabilization system if the in-place stabilization option is used.

3.3.1.5 Characterization of the Wastes

The bulk of UMTRAP wastes will be the tailings themselves. These are sands and slimes from the crushing and milling process. Additional wastes will consist of contaminated soils--from the sites and those contaminated by wind-blown tailings--stabilization materials, riprap, and miscellaneous contaminated rubble and machinery from the mills. Table 3-6 summarizes the quantities of waste displayed in Tables 3-4 and 3-5. The tailings and the contaminated soil below them are given separately because they will not require disposal if on-site stabilization is used. The average Ra-226 concentration in the tailings and contaminated soil below them is given, assuming they are completely mixed, as might happen during removal. These concentrations are of interest in estimating the performance of disposal sites at which they may be placed. No similar concentrations are available for the other wastes but, with the possible exception of the small quantity of ore at the Lowman site, they will generally be considerably lower than the 500 pCi/g calculated as the weighted average for the tailings.

A large portion of the wastes in the right hand column of Table 3-6 will have a physical form similar to soil and tailings. There will also be rubble from demolished buildings, riprap, etc.

In addition to uranium, thorium, radium and their daughters, the wastes from the UMTRAP program will contain small concentrations of a number of other elements. Table 3-7 gives an assay of composite samples from the uranium and vanadium tailings at the reference site in Mexican Hat, Utah, taken from FBD81. The estimate of uranium content is based on

TABLE 3-6

SUMMARY OF POTENTIAL WASTES FROM UMTRAP

State	Processing Site/ Location	Weight of Tailings and Contaminated Soil Below (10^3MT)*	Average Ra-226 in Tailings and Soil (pCi/g)	Other Waste (10^3MT)
Arizona	Monument Valley	1,300	42	--
	Tuba City	850	760	89
Colorado	Durango	1,500	630	550
	Grand Junction	2,000	660	700
	Gunnison	770	270	80
	Maybell	2,500	260	91
	Naturita	730	660	--
	New Rifle	2,700	800	1
	Old Rifle	410	860	9
	Slick Rock (NC)	74	350	6
	Slick Rock (UC)	450	490	18
Idaho	Lowman	100	360	5
New Mexico	Ambrosia Lake	3,100	490	--
	Shiprock	1,900	540	1000
North Dakota	Belfield	0	--	46
	Bowman	0	--	42
Oregon	Lakeview	320	160	--
Pennsylvania	Canonsburg	530	--	14
Texas	Falls City	3,300	310	550
Utah	Green River	170	520	11
	Mexican Hat	2,500	630	20
	Salt Lake City	2,200	710	920
Wyoming	Baggs	--	--	--
	Converse County	200	280	--
	Riverton	1,300	360	370
		Total=29,000+	Weighted Average=500	Total=4,500+

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* For Grand Junction, Naturita, Shiprock, Salt Lake City, and Riverton the weight of contaminated soil under the tailings is from FBDU. All others assume 1 meter of soil below the tailings is contaminated and the soil density is 1.7 MT/m^3.

TABLE 3-7

ASSAY OF COMPOSITE TAILINGS SAMPLES AT MEXICAN HAT*

Element	Percent By Weight
Aluminium	1.0 to 0.01
Arsenic	0.0063
Barium	0.0012
Boron	<0.01
Cadmium	0.00007
Calcium	1.0 to 0.01
Chronium	0.0001
Cobalt	0.0079
Copper	0.0488
Cyanide	<0.000001
Gallium	<0.01
Iron	0.0365
Lead	0.0048
Magnesium	1.0 to 0.01
Manganese	1.0 to 0.01
Mercury	<0.0000001
Molybdenum	<0.01
Nickel	<0.01
Potassium	<0.01
Selenium	0.0006
Silica	>1.0
Silver	0.0001
Titanium	<0.01
Uranium (U_3O_8)	0.02
Vanadium (V_2O_5)	0.135
Zinc	0.0057

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* Abstracted from FBD81.

AEC records. Of particular interest at some UMTRAP sites is release of elements such as arsenic, mercury and selenium from stabilized mill tailings.

The acidity of the tailings and the soils surrounding the tailings are also of interest in designing adequate means of disposing of the waste from UMTRAP sites. Many of the mills used acid-based processes to extract uranium from the ores. Consequently, the tailings have low pH and the mobility of both chemical and radioactive pollutants is enhanced. Analyses of the performance of waste disposal systems that are based on neutral solutions can predict much lower concentrations of effluents near the disposal sites.

The principal isotope of concern in disposing of waste from UMTRAP sites is radium-226. It is toxic when ingested and gives off radon gas when it decays. About 90 percent of the original uranium in the ore is removed during the milling process but the thorium and radium remain. Even if the tailings are reprocessed to remove more of the uranium (an unlikely scenario in the near future; see the following section) the radium content of the wastes will not change.

Assuming secular equilibrium between the uranium and its daughters, the specific activity of thorium in the tailings is the same as that of the radium. Also, the presence of the thorium, the parent of radium, assures that the specific activity of the radium will remain at its current value much longer than if the waste contained radium alone.

Table 3-4 shows that the average specific activity of Ra-226 in the tailings ranges from 50 pCi/g to 1000 pCi/g. Table 3-6 shows that the weighted average (e.g., the average over the entire amount from UMTRAP) of tailings and the contaminated soil beneath them is about 500 pCi/g.

Uranium, thorium, radium and their daughters are essentially the only radionuclides of concern in UMTRAP wastes.

3.3.1.6 Residual Materials

There will be very few residual materials from the D&D of UMTRAP sites. Table 3-3 shows that almost all of the mills have been removed from the sites, along with many other structures. Many of the remaining structures have been decontaminated to the point where they are currently occupied. While some additional decontamination or demolition of these buildings will occur it is unlikely that residual materials available for recycle off the site will result.

The economics of current uranium prices and recovery of uranium from the tailings is such that further processing of the tailings is very unlikely.

The potentially recyclable materials currently at the sites consist almost entirely of buildings that are not in use.

3.3.2 Formerly Utilized Sites Remedial Action Program (FUSRAP)

The FUSRAP is a program devoted entirely to D&D of facilities that were used in early Manhatten Engineering District (MED) and Atomic Energy Commission (AEC) operations. DOE implemented the FUSRAP to identify and evaluate the radiological conditions of these sites that were federally, privately and institutional owned and to decontaminate them to current standards. The FUSRAP sites were used primarily for research, processing and storage of uranium and thorium ores, concentrates and residues (DOE80b). Also included in the program are sites used in the Los Alamos plutonium development program and the Trinity atomic bomb test site (DOE80).

In 1942, under the jurisdiction of the U.S. Army, the Manhattan Engineer District (MED) was established as the lead agency in the development of nuclear energy. The authority previously assigned to the Department of the Army's Office of Scientific Research and Development for process development, engineering design, materials procurement, and site selection associated with the nuclear energy program was transferred to the MED. MED headquarters was originally established in New York City and, in 1943, was transferred to Oak Ridge, Tennessee. On December 31, 1946, the MED was deactivated and its responsibilities were transferred to the newly constituted Atomic Energy Commission (AEC).

Initial MED and AEC programs involved extraction of uranium from foreign ores. Pitchblend ore was imported, stored, and transferred to sampling plants and mills and refineries for extraction of the uranium. Some ores were also processed for thorium recovery. Much of the government-sponsored research and development effort was centered at what are now the national laboratories. Commercial firms produced the needed raw materials and some finished products. Most of the materials manufactured during these operations ended up at the Hanford Site in the State of Washington, for use in the production of plutonium. Commercial firms also conducted uranium recovery operations on scrap and salvaged material.

As a result of these operations, materials, equipment, buildings and land became contaminated, primarily with naturally-occuring radionuclides. Most of these buildings and lands were later decontaminated using methods and standards in acceptance at that time. However, since that time radiological exposure criteria, guidelines and standards have tightened requirements for release of facilities for unrestricted use. In addition, documentation on previous decontamination efforts was insufficient to determine the current radiological status of some sites. As a result, FUSRAP was initiated by the AEC in 1974 to identify the formerly utilized sites and evaluate their current radiological status.

Since inception of FUSRAP, principal contractor facilities have been identified and associated contaminated properties evaluated. Activities to identify additional sites are continuing. Any new sites located will probably be subcontractor facilities or areas used for disposal of waste or equipment, particularly disposal locations for wastes from previous decontamination activities (DOE80).

Changes in ownership and land use and absence of licensing requirements before 1955 made location of all FUSRAP sites difficult. In addition, records relating to both site operations and decontamination activities, which were classified for national defense security, had been relocated to Federal records storage centers, and, in some instances, destroyed. The FUSRAP initially included a thorough records search effort to identify potential sites. Because of incompleteness in the records received, and changing radiological protection guidelines, a site survey program was implemented to characterize the radiological conditions at the FUSRAP sites. The DOE Environmental Control Technology Division (now

Environmental and Safety Engineering Division) was assigned the responsibility for the site survey program. Due to the importance of this effort, FUSRAP was formalized, and a generic plan for identifying and surveying sites and resolving any potential radiological programs was drafted. Recent versions of the FUSRAP strategy and generic plan are given in DOE80.

In mid-1979, using the generic plan as a guide, responsibility for FUSRAP activities was divided between the Assistant Secretary for Environmental Protection, Safety and Emergency Preparedness and the Assistant Secretary for Energy Technology (now Assistant Secretary for Nuclear Energy). The Assistant Secretary for Environmental Protection, Safety and Emergency Preparedness is responsible for identifying, characterizing and ultimately certifying the radiological condition of the sites; the Assistant Secretary for Nuclear Energy is responsible for implementing required remedial actions and identifying disposal sites for residual radioactive material.

DOE80 provides a brief summary of the history and current status of 74 formerly utilized sites, selected from a larger number of facilities, that required evaluation by the Environmental and Safety Engineering Division to determine their radiological condition. In addition, three sites controlled by the DOE (Weldon Spring Site, St. Charles County, Missouri, New Brunswick, New Jersey, and the DOE Niagara Falls Storage Site,* Lewiston, New York) and used by the AEC were summarized for completeness. These sites are currently included in the Surplus Facilities Management

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* This facility was one part of the portion of the Lake Ontario Ordnance Works that was used by the AEC. The DOE now controls only 191 of the original 1511 acres.

Program (see Section 3.3.3). Table 3-8 lists the sites described in DOE80. The Environmental and Safety Engineering Division is reviewing information concerning other formerly utilized sites that may eventually require survey work; however, as of March 1982 there were insufficient data to include other sites in the FUSRAP. The summaries in DOE80 have been reviewed by the owners and/or former owners, state representatives, representatives of the involved national laboratories, and cognizant AEC employees.

3.3.2.1 Status

Thirty-five FUSRAP sites that may require remedial action have been identified.* The list of sites is given in Table 3-9 and their locations are shown in Figure 3-3. Of the 35 sites at least 20 have undergone detailed radiological surveys. Remedial action has been completed at Kellex, and waste from that site has been buried at the commercial Barnwell, South Carolina disposal facility run by Chem-Nuclear Systems, Inc. Some remedial action has also been performed at the Middlesex Sampling Plant, consisting of the cleanup of identified off-site properties and movement of the contaminated material to storage areas at the plant site.

The nature of the contamination and the general physical nature of the wastes at the FUSRAP sites has been identified from their history of involvement in MED/AEC programs. The majority of the sites were associated with processing uranium and thorium ores; consequently their contamination

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* Personal communication, Mr. Lea Keller, DOE Oak Ridge Operations, March 23, 1982.

TABLE 3-8

FORMERLY UTILIZED SITES CONSIDERED FOR FUSRAP

State	Site	Location
Alabama	TVA	Muscle Shoals
Arizona	University of Arizona	Tucson
California	Dow Chemical Co.	Walnut Creek
	University of California	Berkeley
Colorado	Colorado School of Mines	Golden
Connecticut	Anaconda Co.	Waterbury
	Bridgeport Brass Co.	Seymour
Delaware	Allied Chemical Corp.	North Claymont
District of Columbia	Former National Bureau of Standards Buildings	Washington
Florida	CF Industries, Inc.	Bartow
	Conserv	Nichols
	Gardinier, Inc.	Tampa
	International Minerals and Chemical Corp.	Mulberry
	U.S. Steel Corp.	Bartow
	W.R. Grace and Co.	Ridgewood
Illinois	Former GSA 39th St. Warehouse	Chicago
	National Guard Armory	Chicago
	Museum of Science and Industry	Chicago
	Olin Corp.	Joliet
	Palos Park Forest Preserve	Chicago
	University of Chicago	Chicago
Indiana	Joslyn Stainless Steels	Fort Wayne
Iowa	Iowa State University	Ames
Maryland	W.R. Grace and Co.	Curtis Bay
Massachusetts	M.I.T.	Cambridge
	Shpack Landfill	Norton
	Ventron Corp.	Beverly
	Watertown Arsenal	Watertown
	Winchester Engineering and Analytical Center	Winchester
Michigan	General Motors Corp.	Adrian
Missouri	Mallinckrodt, Inc.	St. Louis
	St. Louis Airport Storage Site	St. Louis
	Weldon Spring Site	St. Charles County
Nevada	University of Nevada	Reno
New Jersey	E.I. duPont de Nemours and Co.	Deepwater
	Former Kellex Corp.	Jersey City
	Former Middlesex Municipal Landfill	Middlesex
	Former Middlesex Sampling Plant	Middlesex
	New Brunswick Laboratory	New Brunswick
	Princeton University	Princeton
	Former Vitro Laboratories	West Orange
	Westinghouse Electric Corp.	Bloomfield
New Mexico	Acid and Pueblo Canyons	Los Alamos
	Bayo Canyon Area	Los Alamos
	Chupadera Mesa	White Sands Missle Range
	Los Alamos County	Los Alamos

TABLE 3-8 (CONT)

State	Site	Location
New York	Al-Tech Speciality Steel Corp.	Watervliet
	Ashland Oil Company	Tonawanda
	Bethlehem Steel	Lackawanna
	Columbia University	New York
	DOE Niagara Falls Storage Site	Lewiston
	Guterl Special Steel Corp.	Lockport
	Hooker Chemical and Plastics Corp.	Niagara Falls
	Linde Air Products	Tonawanda
	NL Industries, Inc.	Albany
	Seaway Industrial Park	Tonawanda
	Seneca Army Depot	Romulus
	Staten Island Warehouse	Port Richmond
	Former Sylvania-Corning Nuclear Corp., Inc., Metallurgical Laboratory	Bayside
	Union Carbide Corp.	Niagara Falls
Ohio	Battelle Memorial Institute	Columbus
	Former Brush Beryllium Co.	Cleveland
	Clecon Metals, Inc.	Cleveland
	Former duPont Grasselli Plant	Cleveland
	Harshaw Chemical Co.	Cleveland
Oregon	Albany Metallurgical Research Center	Albany
Pennsylvania	Canonsburg Industrial Park	Canonsburg
	Former Pennsylvania Railroad Landfill Site	Burrell Township
	Rhom and Haas Co.	Philadelphia
	Universal Cyclops, Inc.	Aliquippa
	Westinghouse Atomic Power Development Plant	Pittsburgh
Texas	American Oil Co.	Texas City
	Pasadena Chemical Corp.	Pasadena
Utah	University of Utah	Salt Lake City
	U.S. Bureau of Mines	Salt Lake City
Virginia	Former Virginia Carolina Chemical Corp	Richmond

TABLE 3-9

CURRENT FUSRAP SITES

State	Site	Location
California	Gilman Hall University of California	Berkeley
Florida	Conserv, Inc.	Nichols
	Gardenier, Inc.	Tampa
Illinois	Palos Park Forest Preserve	Cook County
	University of Chicago	Chicago
	National Guard Armory	Chicago
	Olin Corporation	Joliet
Iowa	Iowa State University	Ames
Maryland	W.R. Grace and Company	Curtis Bay
Massachusetts	Shpack Landfill	Norton
	Ventron Corporation	Beverly
	Watertown Arsenal	Watertown
Missouri	Mallinckrodt, Inc.	St. Louis
	St. Louis Airport Storage Site	St. Louis
	St. Louis Airport Storage Site Vicinity	St. Louis
New Jersey	E.I. duPont de Neumours and Company	Deepwater
	Kellex Research Facility	Jersey City
	Middlesex Municipal Landfill	Middlesex
	Middlesex Sampling Plant	Middlesex
New Mexico	Acid and Pueblo Canyons	Los Alamos
	Bayo Canyon	Los Alamos
	Chupadera Mesa	White Sands Missile Range
New York	Ashland Oil Company #1	Tonawanda
	Ashland Oil Company #2	Tonawanda
	Guterl-Simmons Steel Corp.	Lockport
	Linde Air Products Division	Tonawanda
	Niagara Falls Storage Site Vicinity	Lewiston
	Seaway Industrial Park	Tonawanda
	Seneca Army Depot	Romulus
	Staten Island Warehouse	Port Richmond
Ohio	Clecon Metals, Inc.	Cleveland
	Harshaw Chemical Company	Cleveland
Oregon	Albany Metallurgical Research Center	Albany
Pennsylvania	Universal Cyclops, Inc.	Aliquippa
Texas	Pasadena Chemical Corp.	Pasadena

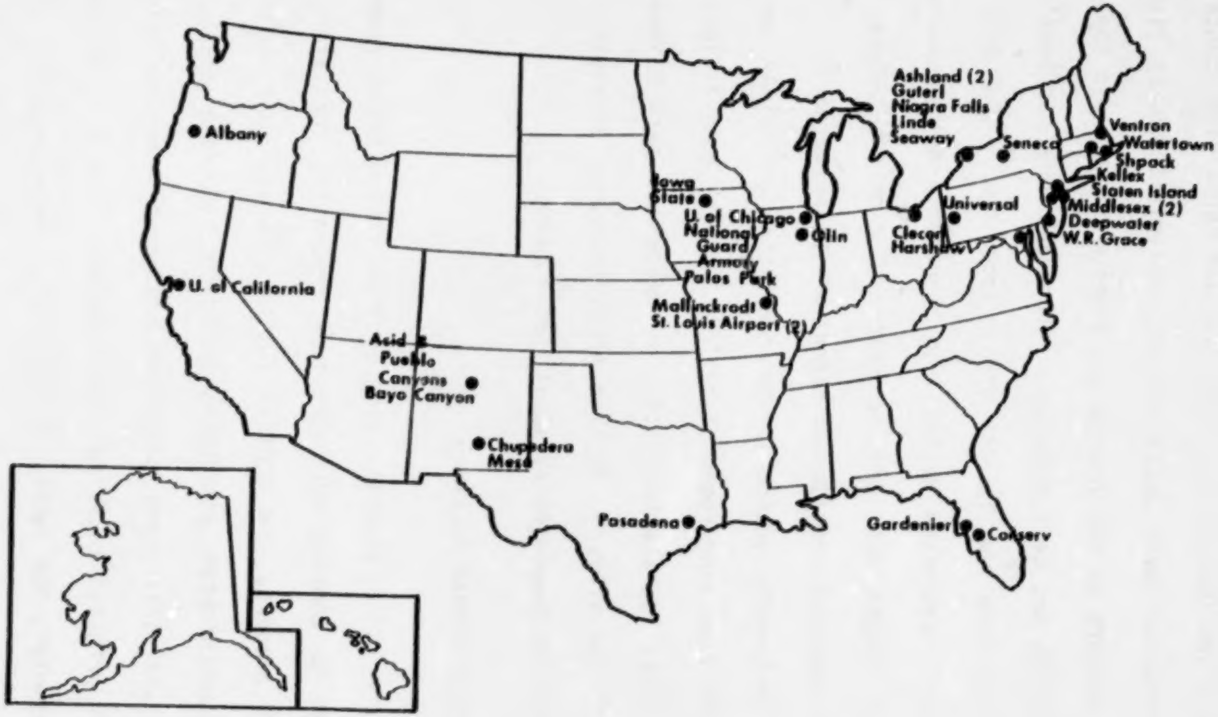
Albany
U. of California
Acid
Pueblo
Canyons
Bayo Canyon
Chupadera
Mesa
Iowa
State
U. of Chicago
National
Guard
Armory
Palos Park
Olin
Mallinckrodt
St. Louis Airport (2)
Pasadena
Ashland (2)
Guterl
Niagra Falls
Linde
Seaway
Seneca
Universal
Clecon
Harshaw
Ventron
Watertown
Shpack
Kellex
Staten Island
Middlesex (2)
Deepwater
W.R. Grace
Gardenier
Conserv
RAE-100386

FIGURE 3-3. LOCATIONS OF FUSRAP SITES

consists entirely of heavy alpha-emitting radionuclides in the uranium and thorium chains. Two sites (University of Chicago and Palos Park) contained nuclear fission devices or their waste and are contaminated with fission products as well as members of the uranium and thorium chains. In the case of Palos Park, plutonium has been detected. Chupedera Mesa has been contaminated with fallout from the Trinity atomic bomb test. The Acid and Pueblo Canyons received untreated wastes from research and processing at Los Alamos and Bayo Canyon was used in tests of high explosives that involved natural and depleted uranium and strontium-90 contamination.

There are no up-to-date schedules for completion of FUSRAP because funding for the major remaining remedial actions has not been included in federal budgets. Also, legislative action is needed to permit remedial action at several of the sites.* Earlier plans indicated an expectation that the program would be completed by about 1990 (DOE80d).

3.3.2.2 Representative FUSRAP Facility

FUSRAP sites are quite diverse, ranging from contaminated rooms in laboratory buildings to complex multistructure processing facilities and associated land and property. A typical FUSRAP site may have initially included 2 or 3 contaminated processing buildings, storage areas, and perhaps a waste disposal area where rubble and equipment from demolition of one or more of the original buildings were buried. The E.I. duPont de Nemours and Co. Deepwater, New Jersey FUSRAP site is representative of the typical facility requiring cleanup. A detailed radiological survey of this site performed by the ORNL for the DOE in March, 1977 is described in DOE78.

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* Personal communication, Mr. Lea Keller, DOE Oak Ridge Operations, March 22, 1982.

The duPont site is located on 700 acres, of which only a portion were used directly in MED/AEC activities. Work there involved development of processes for converting various uranium compounds to metallic, oxide or gaseous forms, and began in the early 1940's. Uranium production activities were completed by the early 1950's, and the site was subsequently decontaminated to standards applicable at the time. Three buildings at the site were involved in the MED/AEC activities. Two of these were demolished and their sites currently are occupied by a new structure and a parking lot. A burial facility at the site accepted contaminated rubble and equipment from the demolished buildings. A considerable amount of contaminated equipment from the initial decontamination efforts was shipped to an off-site AEC storage area for disposal. Disposition and design details of all equipment are not known precisely, but unaccounted for equipment should be of limited immediate health impact concern because the contamination is generally natural uranium and has been cleaned at least once prior to release.

Because of the age and changes in ownership of the generic facilities, little is known of the pre-World War II history of the site's buildings. The building that remains is used as office and warehouse space. Its operating lifetime is estimated to be another twenty years under current uses. The radioactive waste burial area has only limited capacity and use in the future. The radiation survey conducted at the site has indicated that large portions of existing floors, walls and ceilings are moderatly contaminated, with only a few areas exceeding NRC Guidelines for unrestricted release of contaminated property. Some small land areas adjacent to the building have also been shown to be contaminated.

Because the duPont facility handled primarily purified uranium, the results of the radiological survey indicate no major problems with radium or radon gas. (At many of the FUSRAP sites, ore and residues containing considerable amounts of radium were handled. As a result, radon gas concentrations can exceed guideline values at those sites.) Sampling performed during the radiological survey has confirmed that the major contaminant is U-238. Some materials discovered on the floor of the building approach 15 percent by weight uranium. Contaminated soils outside the building range up to about 4 percent uranium, reflecting the effect of mixing and dilution with soil during previous demolition and decontamination activities at the site. Sampling has indicated that the contamination extends downward from the soil surface to about five feet, although some areas are shallower and others have clean soil above the contamination.

At the former disposal site on the property, concentrations of contamination range up to 3 or 4 percent uranium in the samples taken, over an area of about 2000 square feet.

3.3.2.3 Existing Contamination

Qualitative information about contamination at FUSRAP sites has been gathered by reviewing the activities known to have taken place at these locations and by interviewing personnel who worked at the sites. In some cases records of prior radiological surveys and cleanup operations were available. As stated above, about 20 of the 35 sites have undergone detailed radiological surveys since the mid-1970's.

Table 3-10 shows in qualitative terms the nature of the wastes that may come from the FUSRAP sites and the principal radionuclides of concern. It can be seen that most of the potential waste is either soil or rubble. In many cases the rubble results from earlier destruction of buildings and equipment, which was then buried at the site.

Table 3-11, taken from the recent radiological surveys of the reference site (DOE78), is an example of the kind of information gathered during these surveys. Summaries of the findings of the surveys at this site and twelve others are given in Appendix F of DOE81a. The other twelve sites are:

Conserv
Palos Park
Watertown Arsenal
St. Louis Airport Storage Site
Middlesex Sampling Plant
Bayo Canyon
Linde
Ashland #1
Seaway
Seneca
Guterl
Clecon

Radiological surveys have also been made at the following FUSRAP sites:

TABLE 3-10

ESTIMATES OF FUSRAP WASTES
(Source: DOE81a)

State	Site	Principal Constituents	Contaminants
California	University of California	Floor Tile, Piping	Alpha, ^{137}Cs
Florida	Conserv	Soil, Concrete	^{238}U, ^{226}Ra
	Gardinier	Soil, Pipes, Tanks, Rubble	^{238}U, ^{226}Ra
Illinois	Palos Park	Soil, Rubble	Tritiated Water, ^{238}U, ^{239}Pu, ^{155}Eu ^{137}Cs, ^{90}Sr, ^{60}Co
	University of Chicago	Building Interior Rubble	
	National Guard Armory	Building Interior Rubble	Alpha
	Olin	Building Interior Rubble	^{238}U, ^{226}Ra
Iowa	Iowa State	Soil, Building Interior Rubble	^{238}U, ^{232}Th
Maryland	W.R. Grace	Soil	^{232}Th
Massachusetts	Shpack	Soil, Concrete, Metal, Rubble	^{238}U, ^{226}Ra
	Ventron	Soil, Rubble	^{238}U
	Watertown	Soil, Concrete	^{238}U, ^{232}Th, ^{226}Ra, ^{137}Cs
Missouri	St. Louis Airport	Soil	^{238}U, ^{230}Th, ^{226}Ra
	St. Louis Airport Vicinity	Soil	^{238}U, ^{230}Th, ^{226}Ra
	Malinckrodt	Soil, Building Material, Rubble	^{238}U, ^{230}Th
New Jersey	Deepwater	Soil, Building Material, Rubble, Road Material	^{238}U, ^{232}Th, ^{226}Ra, ^{210}Pb
	Kellex	Soil	^{238}U
	Middlesex Landfill	Soil	^{238}U
	Middlesex Sampling Plant	Soil, Building Material, Rubble	^{238}U, ^{232}Th, ^{226}Ra

TABLE 3-10 (CONT)

State	Site	Principal Constituents	Contaminants
New Mexico	Acid and Pueblo Canyons	Soil	^{239}Pu, ^{241}Am, Fission Products
	Bayo Canyon	Soil, Building Material, Rubble	^{238}U, ^{90}Sr
	Chupadera Mesa	Soil	Fission Products
New York	Ashland #1	Soil	^{238}U, ^{232}Th, ^{226}Ra
	Ashland #2	Soil	^{238}U, ^{232}Th, ^{226}Ra
	Guterl	Soil, Building Equipment, Rubble	^{238}U, ^{232}Th, ^{226}Ra, ^{224}Ra
	Niagara Falls Storage Site Vicinity	Soil	^{238}U
	Linde	Soil, Building Material, Equipment	^{238}U, ^{232}Th, ^{230}Th, ^{226}Ra
	Seaway	Soil	^{238}U, ^{232}Th, ^{230}Th, ^{228}Th, ^{226}Ra
	Seneca	Soil, Building Material	^{238}U, ^{232}Th, ^{226}Ra, ^{40}K
	Staten Island		Uranium Ore
Ohio	Clecon	Soil, Building Material	^{238}U, ^{232}Th, ^{228}Th
	Harshaw	Soil, Building Material	^{238}U
Oregon	Albany	Soil, Building Material, Plumbing	^{238}U, ^{232}Th
Pennsylvania	Universal	Soil, Building Material	^{238}U
Texas	Pasadena	Sink and Drain (DOE80)	Uranium Processing Wastes

TABLE 3-11

SUMMARY OF THE RADIOLOGICAL SURVEY OF THE DEEPWATER, N.J. FUSRAP SITE
(Sources: DOE81a and DOE78)

Survey Location	Radioactivity		
	Type	On Site	Off Site
Building Interior (floors)	Alpha	1-10 dpm/cm^2	
Building Interior (walls)	Alpha	2-5 dpm/cm^2	
Building Interior (floors)	Gamma	4-11 μR/h	
Parking Lot	Gamma	4-5 μR/h	
Soil	Gamma	4-23 μR/h	3-6 μR/h
Surface Soil	^{238}U	1-12,600 pCi/g	0.3-4 pCi/g
Surface Soil	^{226}Ra	0.4-0.7 pCi/g	0.2-0.9 pCi/g
Surface Soil	^{232}Th	0.4-0.8 pCi/g	0.3-1.0 pCi/g
Subsurface Soil	^{238}U	0-11,200 pCi/g	
Subsurface Soil	^{226}Ra	0-18 pCi/g	
Subsurface Soil	^{232}Th	0-1.8 pCi/g	
Groundwater	^{238}U	0.7-250 pCi/l	0.43-1.5 pCi/l
Groundwater	^{226}Ra	0.14-1 pCi/l	<0.009-0.023 pCi/l
Groundwater	^{230}Th	0.2-3.8 pCi/l	0.015-0.032 pCi/l
Groundwater	^{210}Pb	3.2-10 pCi/l	<0.45-0.9 pCi/l

Notes:

Gamma measurements were taken 1 meter above the surface.
Off-site measurements were taken at points sufficiently removed from the formerly utilized site that they were not influenced by site operations.
Surface soil samples were taken at depths of 5 cm or less.
Subsurface soil samples were taken at depths of 1 to 4.5 meters.
Off-site water samples taken from the Delaware River.

Gardenier (Ha81)
Mallinckrodt (Go81)
Shpack (Co81)
Kellex (Be82)
Middlesex Landfill (DOE80f)
Acid and Pueblo Canyons (LA81)

and for off-site properties near Middlesex, New Jersey (Le81). Appendix F of DOE81a summarizes radiological surveys of the following sites that are no longer of prime concern in FUSRAP:

GSA 39th Street Warehouse, Chicago, Illinois
Museum of Science and Industry, Chicago, Illinois
Hooker Chemical Co., Niagara Falls, New York
Former Pennsylvania Railroad Landfill, Burrell
Township, New Jersey

3.3.2.4 D&D Procedures

As with UMTRAP, procedures for reducing radiological risks at FUSRAP sites focus on two options:

- Stabilization in place
- Removal and shallow burial

A third option, ocean disposal, is also being considered for disposal of wastes at the Middlesex Sampling Plant. The two major options both lead to something like an ENTOMB condition,* but DECON activity will be necessary at many of the sites where contamination levels in buildings or soils near the surface exceed acceptable levels. Table 3-12 shows the D&D procedures recommended for each FUSRAP site. Most of the information comes from

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* The condition is like the ENTOMB option described in Chapter 2, but there is little assurance that burial will isolate the wastes until they decay to an unrestricted level.

TABLE 3-12

RECOMMENDED D&D PROCEDURES
(Source: DOE80b, unless otherwise noted)

State	Site	In Place Stabilization	Excavation of Soils	Decontamination of Buildings, etc	Removal of Plumbing, etc
California	University of California			X	X
Florida	Conserv		X	X	
	Gardenier		X	X	X
Illinois	Palos Park		X	X	
	University of Chicago		X	X	
	National Guard Armory		X	X	
	Olin			X	
Iowa	Iowa State		X	X	
Maryland	W.R. Grace		X		
Massachusetts	Shpack		X		
	Ventron		X	X	
	Watertown		X	X	
Missouri	Mallinckrodt		X	X	X
	St. Louis Airport	X or	X		
	St. Louis Airport Vicinity		X		
New Jersey	Deepwater		X	X	
	Kellex			X	
	Middlesex Landfill	X	X		
	Middlesex Sampling Plant		X		
New Mexico	Acid and Pueblo Canyons	X or	X		
	Bayon Canyon	X or	X		
	Chupadera Mesa	X			
New York	Ashland #1		X		
	Ashland #2		X		
	Guterl		X	X	X
	Linde		X	X	
	Niagara Falls Storage Site Vicinity	---	---	---	---
	Seaway		X		
	Seneca		X	X	
	Staten Island		X		
Ohio	Clecon		X	X	X
	Harshaw		X	X	
Oregon	Albany		X	X	X
Pennsylvania	Universal		X	X	
Texas*	Pasadena				X

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* Deduced from descriptions of contamination given in DOE80.

DOE80b. Only temporary measures are given in DOE80b for the Niagara Falls site.

If stabilization in place is the option selected only small volumes of materials will need to be moved over short distances. Typically, prior disposal sites will be reopened to accept small additional amounts of contaminated soils and rubble, as well as contamination removed from surfaces of nearby buildings. The latter may take the form of stripable paint, wood or concrete scrapings, wood shavings, residues from evaporated cleaning fluids, etc, depending on the method used to remove the surface contamination. The old disposal sites will then be covered with materials of the right kind to prevent unacceptable releases into the atmosphere and water.

If some or all contaminated materials are removed from the site for burial elsewhere, apropriate disposal facilities will have to be located and developed. These can be dedicated facilities that only receive wastes from one or more FUSRAP sites or they may receive wastes from other sources, such as UMTRAP wastes or commercial low-level radioactive wastes. Generally, the nature and volumes of the FUSRAP wastes are such that they may be candidates for co-disposal of this kind (see below).

3.3.2.5 Characterization of the Wastes

Table 3-13 indicates the volumes of wastes anticipated from most of the FUSRAP sites when the D&D methods listed in Table 3-12 are implemented.

TABLE 3-13

ESTIMATED VOLUMES OF FUSRAP WASTES
(Source: DOE81a, unless otherwise noted)

State	Site	Waste Volume (m^3)
California	University of California	60*
Florida	Conserv	100
	Gardinier	1,500
Illinois	Palos Park	16,000
	University of Chicago	75**
	National Guard Armory	19
	Olin	230**
Iowa	Iowa State	46
Maryland	W.R. Grace	20,000
Massachusetts	Shpack	3,400
	Ventron	76
	Watertown	200
Missouri	Mallinckrodt	38,000
	St. Louis Airport	140,000
	St. Louis Airport Vicinity	
New Jersey	Deepwater	2,100
	Kellex	0
	Middlesex Landfill	69,000
	Middlesex Sampling Plant	60,000*
New Mexico	Acid and Pueblo Canyons	1,300
	Bayo Canyon	6,200**
	Chupadera Mesa	--
New York	Ashland #1	37,000
	Ashland #2	
	Guterl	270
	Linde	38,000
	Niagara Falls Storage Site Vicinity	--
	Seaway	30,000
	Seneca	310
	Staten Island	--
Ohio	Clecon	610
	Harshaw	7,000
Oregon	Albany	2,800
Pennsylvania	Universal	42
Texas*	Pasadena	--
	Total	470,000+

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* Adjusted according to a personal communication with Ms. K. Hara, DOE Oak Ridge Operations, March 23, 1982.

** Source is DOE80b.

Of the 35 FUSRAP sites, 34 of which may produce wastes,* three sites--the St. Louis Airport Storage Site and its vicinity, Middlesex Landfill and the Middlesex Sampling Plant--provide about 57 percent of the waste volume. Ninety-two percent of the waste volume is generated by the 8 sites having 20,000 m^3 or more of waste.

To put these volumes in some perspective, the total estimated volume of FUSRAP wastes is less than the estimated volume of tailings at most of the individual UMTRAP sites (see Table 3-4). While not as potentially uniform in makeup as the tailings from UMTRAP, most of the FUSRAP wastes are shown in Table 3-10 to consist of contaminated soil, building material or rubble. A more detailed breakdown is not available.

The radiological characteristics of FUSRAP wastes will be dominated by the presence of naturally occurring radionuclides of the uranium decay chain. Table 3-10 shows 6 sites that may generate waste with other radionuclides. The waste from these sites is about 5 percent of the total FUSRAP wastes. Concentrations of activity will depend on the amount of soil and other materials mixed with the high concentration residues. For the reference site, peak concentrations on the order of eleven to twelve thousand pCi/g of ^{238}U were measured in soils during the radiological survey (see Table 3-11), but average values were at least an order of magnitude lower (DOE81a). No significant volumes of transuranic wastes (currently defined as 10 nCi/g of transuranic nuclides) are anticipated to result from FUSRAP D&D. The concentration limits stated in Draft 10CFR61

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* Chupadera Mesa is only being considered for in-place stabilization.

(NRC81c) permit disposal of wastes containing transuranics with concentrations less than 10 nCi/g in shallow land disposal sites.*

Besides uranium, most of the FUSRAP sites are contaminated with thorium-230 and radium-226. Those sites that were used primarily for processing uranium will have little activity from thorium and radium because the latter two nuclides will have been removed in milling. However, sites that stockpiled uranium ores are likely to have similar activities of all three and those that contain residues of uranium extraction will have higher levels of thorium and radium. An example of the latter is the St. Louis Storage Site where high radium concentrations (up to 1300 pCi/g) were measured by Oak Ridge National Laboratory (Ha78).

3.3.2.6 Residual Materials

Table 3-12 indicates that the FUSRAP program will involve decontamination of buildings at at least 20 of the 35 sites. Many of these buildings are in current use, but further decontamination is necessary. Seven sites will require removal of plumbing and other fixtures, ranging from a contaminated sink and drain at the Pasadena site to underground pipes and tanks at the Gardinier site. The contamination is likely to be on the surface of the equipment only, indicating that decontamination is possible. It is not known whether equipment of this nature will have residual value.

Some of the contaminated soils at the sites may have potential uranium values but their small volumes and the distances they must be transported to uranium mills will probably make them unusable as uranium ores.

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* If other radioisotopes are also present in the waste allowance must be made for their presence. See NRC81c.

3.3.3 Surplus Facilities Management Program (SFMP)

The SFMP involves D&D of facilities currently owned by the DOE. The following description of the program is abstracted in part from DOE81a and DOE82a. There have been recent changes in the organization of DOE. Updated information on the management and status of facilities may be obtained from DOE.

The SFMP includes approximately 500 DOE "facilities" (DOE81a, DOE82a) that are surplus, or will become surplus in the near future. These facilities, located throughout the United States and in Puerto Rico, range in complexity and size from reactors and support facilities, solid waste disposal areas, fuel reprocessing facilities and laboratory facilities to stacks, tanks, pipelines, waste treatment systems, ponds, cribs, ditches and areas containing uranium and thorium residues. In the terminology of SFMP, the facilities are aggregated into 90 disposition "projects"--36 in the "commercial program" and 54 in the "defense program". Tables 3-14 and 3-15 list the SFMP projects alphabetically by DOE field office responsible for the project. Further details on these projects are contained in DOE82a. The tables list two sites scheduled for completion of D&D in FY82: The Westinghouse Facility and the Advanced Fuels Laboratory. It does not include three sites where SFMP monitors entombed reactors: Hallum, Nebraska, Piqua, Ohio and the BONUS Site at Rincon, P.R.

3.3.3.1 Status

It can be seen from Tables 3-14 and 3-15 that all the SFMP facilities and projects are contained at the 19 separate locations shown in Figure 3-4. The objectives of the SFMP are to decontaminate these facilities and to eliminate any potential hazards to public health and the environment. The program is scheduled for completion by the year 2000. Waste from the SFMP will primarily be low-level waste, but some transuranic (TRU) waste will also be produced. Projected volumes of this waste are given in Section 3.3.3.5. Approximately 73 percent of the low-level waste will come from the Monticello site in Utah and another 20 percent from the Weldon Spring, Missouri, and Niagara Falls, New York sites. The largest portion of the currently estimated TRU waste, approximately 75 percent, will be generated in Washington State in decommissioning several plutonium production reactors and reprocessing facilities. The total volume of low-level waste for all SFMP activities is projected to be at least 1.5×10^6 m^3; the TRU volume is projected to be at least 9000 m^3.

Projections for SFMP waste are very preliminary and assume a worst case (i.e., all waste generated from decommissioning operations will be contaminated and require disposal at a radioactive waste disposal site). Waste volumes have not yet been estimated for many facilities. The projections will be modified depending on federal release limit criteria, more detailed radiological characterizations of the SFMP facilities, and the selection of a disposition mode for each facility. Waste volume reduction and decontamination techniques will be employed on an individual project basis as practicable, and will further affect waste estimates and categorization.

TABLE 3-14

SFMP PROJECT, COMMERCIAL PROGRAM

Source: DOE82a

DOE Field Office Project	Project Site	State	Category
Albuquerque			
Mound ANSPD Areas	Mound	OH	Plutonium Laboratory
LAPRE II Vessel	Los Alamos NL	NM	Reactor
Ta-2 Water Boiler Reactor	Los Alamos NL	NM	Reactor
UHTREX	Los Alamos NL	NM	Reactor
Chicago			
Building 350 (Pu Gloveboxes)	Argonne NL	IL	Plutonium Laboratory
Pu Fuel Fabrication Facility	Westinghouse	PA	Plutonium Laboratory
ANL-East Surplus Facilities	Argonne NL	IL	Waste Treatment
Juggernaut Reactor	Argonne NL	IL	Reactor
Experimental BWR	Argonne NL	IL	Reactor
Idaho			
Monticello Site	Monticello	UT	Uranium Mill
SPERT III Ancillary Facilities	Idaho Nat. EL	ID	Ground Disposal Facility
SPERT II Ancillary Facilities	Idaho Nat. EL	ID	Ground Disposal Facility
SPERT I Ancillary Facilities	Idaho Nat. EL	ID	Ground Disposal Facility
SPERT I Test Facility	Idaho Nat. EL	ID	Reactor
SPERT IV Ancillary Facilities	Idaho Nat. EL	ID	Ground Disposal Facility
Boiling Water Reactor Exper. V	Idaho Nat. EL	ID	Reactor
Nevada			
Nuclear Rocky Development Sta.	Nevada Test Site	NV	Reactor
Oak Ridge			
CEER Mayaquez	Center for Energy and Environmental Research	PR	Reactor/Laboratory
Niagara Falls Storage Site	Niagara Falls	NY	Ground Disposal Facility
Weldon Spring Site	Weldon Spring	MO	Ground Disposal Facility
Molten Salt Reactor Experiment	Oak Ridge NL	TN	Reactor
Low Intensity Test Reactor	Oak Ridge NL	TN	Reactor
Rector Experimental Facilities	Oak Ridge NL	TN	Reactor
Radioactive Process & Waste Fac.	Oak Ridge NL	TN	Reactor
Homogeneous Reactor Experiment No. 2	Oak Ridge NL	TN	Reactor
Waste Tanks	Oak Ridge NL	TN	Tanks
Richland			
Shippingport Atomic Power Station	Shippingport	PA	Reactor
San Francisco			
Sodium Reactor Experiment	Santa Susana Field Lab.	CA	Reactor
Advanced Fuels Laboratory	Vellecitos	CA	Plutonium Laboratory
Nuclear Material Dev. Facility	Santa Susana FL	CA	Laboratory
SNAP 8 Test Facility	Santa Susana FL	CA	Reactor
Nuclear Dev. Test Facility	Santa Susana FL	CA	Reactor
Radioactive Mat. Disposal Fac.	Santa Susana FL	CA	Waste Treatment Facility
Interim Storage Facility	Santa Susana FL	CA	Storage
UC-Davis Waste Retention System	UC Davis	CA	Tanks/Ground Disposal Facility
Savannah River			
Heavy Water Comp. Test Reactor	Savannah River	SC	Reactor

TABLE 3-15

SMFP PROJECT, DEFENSE PROGRAM

Source: DOE82a

DOE Field Office Project	Project Site	State	Category
Albuquerque			
SM Building	Mound	OH	Plutonium Laboratory
Sanitary Disposal Facility	Mound	OH	Waste Treatment
Chicago			
New Brunswick Laboratory	New Brunswick	NJ	Laboratory
Idaho			
Liquid Waste Evaporator (PM-2A)	Idaho Nat. EL	ID	Waste Treatment
Surplus CPP Facilities	Idaho Nat. EL	ID	Chemical Processing Plant
Materials Test Reactor (MTR)	Idaho Nat. EL	ID	Reactor
TAN-TECH Support Facilities	Idaho Nat. EL	ID	Waste Treatment
Heat Transfer Reactor Experiment	Idaho Nat. EL	ID	Reactor
Army Reentry Vehicle Facility Site	Idaho Nat. EL	ID	Storage
Initial Engine Test Facility	Idaho Nat. EL	ID	Reactor
ARA I and II	Idaho Nat. EL	ID	Reactor
ARA III and Leach Pond	Idaho Nat. EL	ID	Ground Disposal Facility
ARA IV	Idaho Nat. EL	ID	Reactor
MTR 756 Leach Pond	Idaho Nat. EL	ID	Ground Disposal Facility
Oak Ridge			
ILW Transfer Line	Oak Ridge NL	TN	Waste Treatment
Curium Facility	Oak Ridge NL	TN	Laboratory
Metal Recovery Facility	Oak Ridge NL	TN	Chemical Processing Plant
Fission Products Dev. Lab.	Oak Ridge NL	TN	Chemical Processing Plant
Waste Holding Basin (3513)	Oak Ridge NL	TN	Waste Treatment
Old Hydrofracture Facility	Oak Ridge NL	TN	Waste Treatment
Gunite Tanks	Oak Ridge NL	TN	Waste Treatment
Graphite Reactor	Oak Ridge NL	TN	Reactor
Richland			
108-F Biological Laboratory	Hanford	WA	Laboratory
100-F Production Reactor	Hanford	WA	Reactor
Strontium Semiworks	Hanford	WA	Chemical Processing Plant
100-H Production Reactor	Hanford	WA	Reactor
233-S Pu Concentration Facility	Hanford	WA	Plutonium Laboratory
Redox Reprocessing Plant	Hanford	WA	Chemical Processing Plant
216-Z-9 Crib	Hanford	WA	Ground Disposal Facility
Gable Mountain Storage Vaults	Hanford	WA	Storage
100-D/DR Production Reactors	Hanford	WA	Reactor
Z Plant Ground Disposal Facility	Hanford	WA	Ground Disposal Facility
Redox Ground Disposal Facilities	Hanford	WA	Ground Disposal Facility
T Plant Reprocessing Facilities	Hanford	WA	Chemical Processing Plant
216-T Ground Disposal Facilities	Hanford	WA	Ground Disposal Facility
200-E Ground Disposal Facilities	Hanford	WA	Ground Disposal Facility
U Plant Reprocessing Facilities	Hanford	WA	Chemical Processing Plant
216-B Ground Disposal Facilities	Hanford	WA	Ground Disposal Facility
Z Plant Reprocessing Facilities	Hanford	WA	Waste Treatment
Metal and Fuel Storage Basins	Hanford	WA	Chemical Processing Plant
Cesium Loadout Facilities	Hanford	WA	Chemical Processing Plant
300 Area Waste Facilities	Hanford	WA	Ground Disposal Facility
200 Area Peripheral Waste Fac.	Hanford	WA	Ground Disposal Facility
Purex Ground Disosal Facilities	Hanford	WA	Ground Disposal Facility
T Plant Ground Disposal Fac.	Hanford	WA	Ground Disposal Facility
B & C Crib & Trench Field	Hanford	WA	Ground Disposal Facility
200 W Misc. Ground Disposal Fac.	Hanford	WA	Ground Disposal Facility
U Plant Ground Disposal Fac.	Hanford	WA	Ground Disposal Facility
244-B Concentration Building	Hanford	WA	Plutonium Laboratory
216-A Ground Disosal Fac.	Hanford	WA	Ground Disposal Facility
Silica Gel Bldg. & Sample House	Hanford	WA	Chemical Processing Plant
Misc. Ground Disposal Facilities	Hanford	WA	Ground Disposal Facility
Schenectady Naval Reactors			
Separations Process Research Unit	Knolls Atomic PL	NY	Chemical Processing Plant

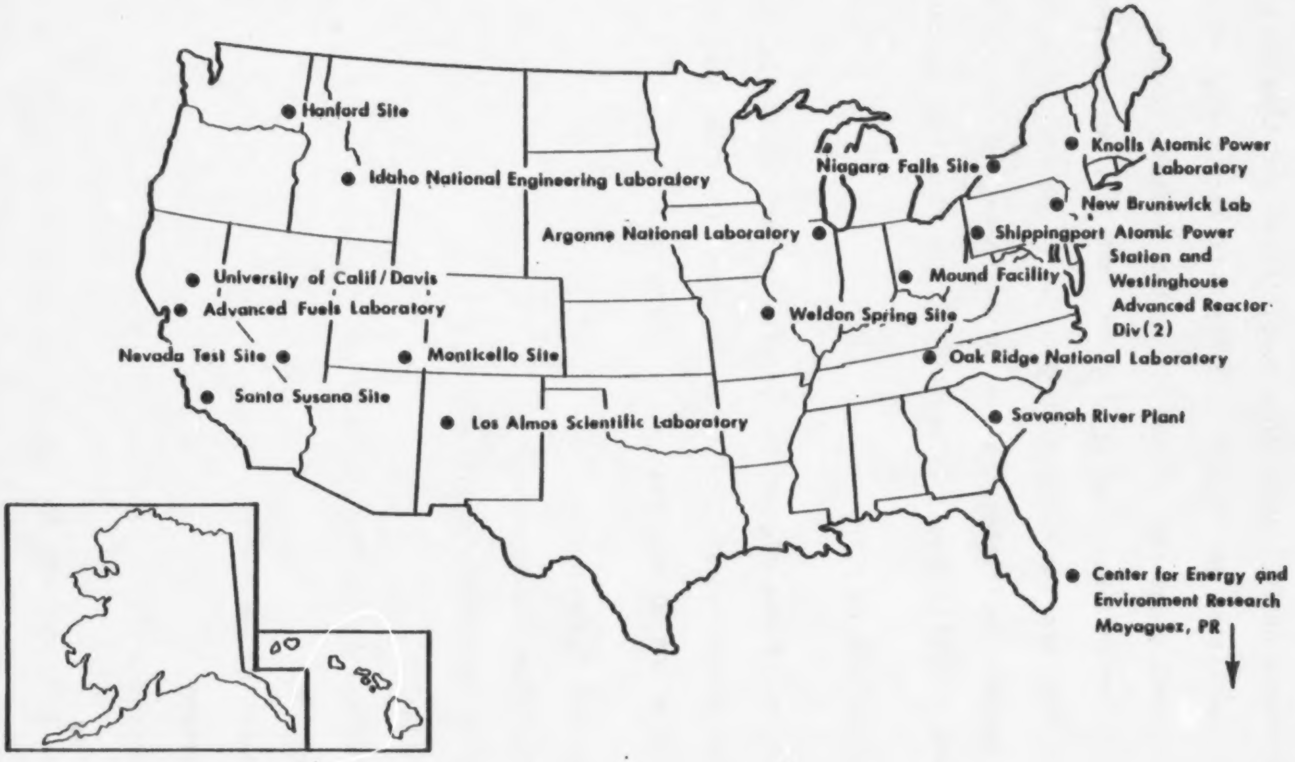
Hanford Site
Idaho National Engineering Laboratory
University of Calif/Davis
Advanced Fuels Laboratory
Nevada Test Site
Santa Susana Site
Monticello Site
Los Almos Scientific Laboratory
Argonne National Laboratory
Weldon Spring Site
Niagara Falls Site
Knolls Atomic Power Laboratory
New Brunswick Lab
Shippingport Atomic Power Station and Westinghouse Advanced Reactor Div(2)
Mound Facility
Oak Ridge National Laboratory
Savannah River Plant
Center for Energy and Environment Research Mayaguez, PR
RAE-100385

FIGURE 3-4. LOCATIONS OF SFMP SITES

A number of facilities similar to those in the SFMP program have been decommissioned. Reference NRC79 listed those completed at the time of its publication. Those facilities are listed in Table 3-16 for completeness. While there are no current plans for further D&D at those sites, changes in cleanup criteria and standards may some day require that they be reworked. References Ko78 and Fa80 are annotated bibiographies of reports covering decommissioning of nuclear facilities. While there are many documents on D&D procedures, there is little direct information on the resultant wastes.

3.3.3.2 Representative SFMP Facility

It is difficult to choose one or two representative facilities for SFMP because of the diversity of facilities included in that program. Reference DOE82a divides the 90 projects into 9 categories:

- General laboratories
- Plutonium laboratories
- Waste treatment facilities
- Tanks
- Chemical processing plants
- Reactors
- Ground disposal facilities
- Storage
- Uranium mills

Tables 3-14 and 3-15 indicate the categories for each project. Only one project (Monticello) falls into the last category. The largest number of projects (27) are classified as reactors. Twenty-five projects are

TABLE 3-16

FACILITIES KNOWN TO HAVE BEEN DECOMMISSIONED
Source: NRC79

Site	Facility	Year Completed
Elk River, Minn.	Elk River Reactor	1974
Hallum, Neb.	Hallum Nuclear Power Facility	1969
Hanford Site, Wash.		
100-H Area	Pump House, No. 1907-H	1976
200 East Area	Maintenance Shop Building, No. 272-C	1974
	Laundry Storage SWP, No. 2724-C	1973
200 West Area	Stack Gas Monitoring Station, No. 2712-S	1967
	Contaminated Equipment Maintenance, No. 2713-S	1967
	P-11, No. 1120 Pu Contaminated Laboratory	1975
	Redox Reprocessing Plant, Roof Repair Only	1978
300 Area	Hanford Test Reactor (HTR), No. 305	1977
Idaho Nat. Eng. Lab., Idaho	Organic Moderated Reactor Experiment Facility	1979
	Experimental Breeder Reactor No. I. (EBR-I) Complex	1972
	Material Test Reactor Working Reservoir	1975
Los Alamos Nat. Lab., N.M.	Experimental Building, TA-33-21	1975
	Filter Building, TA-21-153	1979
	Incinerator Site, TA-42	1978
	Tritium Glove Box Line, TA-35-2	1979
Carlsbad, N.M.	Carlsbad Site Plowshare	1980 (projected)
Piqua, Ohio	Piqua Nuclear Power Facility	1969
Punta Higuera, P.R.	BONUS Reactor	1970
Rio Blanco Test Site, Co.	Rio Blanco Site Facilities	1976
Rulison Site, Co.	Rulison Site Facilities	1976
Santa Susana Field Lab, California	SNAP Experimental Reactor Facility, Building No. 10	1978
	Shield Test Irradiation Reactor (STIR) No. 28	1976
	Kinetics Experimental Water Boiler (KWEB) No. 73	1975
	Hot Cave, Building 003	1975
	S8ER, Building 010	1978

classified as ground disposal facilities. Two (the Center for Energy and Environmental Research in Mayaguez, P.R., and the UC Davis waste retention system) have been assigned dual categories.

To provide some understanding of considerations involved in D&D actions under SFMP the following description of a Hanford plutonium production reactor, such as the 100-F reactor, and its decommissioning is taken from Wa79.

A typical retired Hanford production reactor facility includes the reactor and several support systems and activities which were housed in 32 buildings located in an approximately six square mile area. It includes a pump station located on the banks of the Columbia River through which river water was obtained for fire and sanitary, service, and process needs.

The reactor building contains the reactor block; the reactor control room; a spent fuel discharge pool; fuel storage basin and associated fuel handling equipment; fans and ducts for ventilation and confinement systems; and support offices, shops and laboratories.

Dismantling, packaging and disposal of the reactor block is the greatest challenge in the D&D program. The reactor is a graphite-moderated, water-cooled reactor used for producing weapons-grade plutonium. The core of the block is 28 ft thick, 36 ft high and 36 feet wide and is made up of high-purity graphite blocks.

A thermal shield surrounds the graphite moderator stack on all six sides. The shield is fabricated of cast iron blocks of varying sizes and thickness depending upon location in the reactor assembly. A biological shield surrounds the thermal shield on all sides except the bottom. The shield is made up of alternate layers of steel and masonite and is 52 inches thick. This shield absorbed heat and neutrons that escaped the moderator and thermal shield.

The concrete base of the reactor is overlayed with steel plates which are welded together and to the bottom of the biological shield. While this steel is not a part of the biological shield, it does complete what amounts to a leak-tight steel box which completely encloses the reactor. Neoprene expansion joints are provided at the corners of the shield to allow for thermal expansion of the reactor. The 2004 fuel process channels are lined with aluminum tubes, to which nozzles and connectors are attached to supply cooling to the reactor. The cooling system consisted of a supply manifold made up of 36 inch supply piping and 39 four-inch cross headers.

The cooling water effluent system is essentially a duplicate of the supply piping. The nine water cooled horizontal control rods are 75 feet long. The rod tip or neutron absorbing section is 29.5 feet in length. Twenty-nine vertical safety rods maintained the reactor subcritical after complete Xenon decay and effected a rapid shutdown under emergency conditions. The reactor block measures 46 ft x 40 ft x 46 ft.

The fuel storage basin and transfer area served as a collection, storage and transfer facility for the irradiated fuel elements after they were discharged from the reactor. The basin, which is 81 feet long by 74 feet wide and 20 feet deep, is basically a large water tank which was filled with 18 feet of water during fuel storage. The basin is currently filled with dirt to control the spread of activation products which remain in the storage basin.

There are four buildings (the main reactor building, gas recirculation building, filter building with ventilation exhaust stack and the liquid waste lift station) included in the SFMP D&D plan for the 100-F production reactor D&D Program. Also included are the underground waste burial trenches and cribs in the 100-F location.

A site characterization study was carried out during the 1970s to establish the radionuclide inventories and concentrations in the facilities and ground disposal sites.

As an example of D&D of another SFMP project, Mi79a describes plans for decommissioning the Shippingport power station.

3.3.3.3 Existing Contamination

Little detailed information is available about contamination of SFMP sites. Section A.2 of Appendix A provides some details of contamination at the reference facility plutonium production reactor, abstracted from Wa79. As mentioned above, DOE82a places each SFMP project in one of 9 categories. To some degree the nature of the contamination may be inferred from those categories. Tables 3-14 and 3-15 list the commercial and defense SFMP projects and their categories.

3.3.3.4 D&D Procedures

D&D procedures for the SFMP projects can include ENTOMB, DECON, and SAFSTOR. As mentioned earlier, the SFMP program monitors several entombed reactors. Procedures for disposing of short-lived radionuclides on site during decommissioning of the 100-F area, described in some detail below, include SAFSTOR. The majority of the D&D will probably involve DECON--removal of radioactive material to allow unrestricted use. Some details of plans to decontaminate the reference facility are available in Wa79. They are described in the following paragraphs.

Decontamination of the reactor building will require removing all the reactor support systems such as reactor inlet and outlet piping, vertical safety rods, horizontal control rods, process tubes, etc. This activity also includes decontaminating the surfaces inside the building where radioactivity is found. When this is completed, the only equipment remaining in the building will be the reactor block. Following removal of the reactor block, (see below) the reactor building will be demolished and removed from the site.

Two alternate methods for removing the reactor block are being planned. The preferred method is to seal all the openings in the reactor, install a small water recirculating system and fill the reactor with water to be used as a radiation shield for the workers during dismantling and to facilitate contamination control. A bridge crane will be installed over the top of the reactor to handle the parts of the reactor as it is dismantled. A temporary ventilation control enclosure will be installed for a loadout station. The station will accommodate a railroad car or a truck to transport the contaminated material to the burial site. The enclosure will also have an airlock compartment with a decontamination facility for cleaning the railroad cars and/or trucks before they leave the facility.

The top biological shield will be cut in small sections using an arc-saw and acetylene torch. The sections of shield will be packaged and transferred to the railroad car.

Following removal of the top biological shield, a movable working platform will be mounted on top of the reactor for the crane operator. Removal of the thermal shield, graphite stack blocks and the biological shield will be in a selected sequence to ensure that there is water over the graphite and thermal shield at all times to provide radiation shielding to the workers.

The alternate plan for dismantling the reactor block follows the same general procedure, except the work will be done without flooding the core of the reactor block. This plan would require a shielded control room for the crane operator and an enclosure over the top of the reactor for contamination control.

There are three facilities which support the reactor operation that will also be decommissioned: the gas recirculation facility; ventilation exhaust and confinement system; and the contaminated liquid waste lift station. The equipment and buildings will be decontaminated and disposed of by conventional techniques.

The waste facilities at 100-F Area were utilized during the operating period for disposal of radioactive wastes. There were three different types of disposal sites. The cribs were open-bottomed trenches filled with coarse rock and covered with dirt. They were used to disperse liquid effluent. The leach trenches were open-topped, long, narrow, unlined excavations used to dispose of large volumes of low-level liquid wastes. The burial grounds were excavated trenches in which solid waste was placed and covered with a minimum of four feet of clean earth. There are 3 cribs, 5 trenches and 5 burial grounds listed in DOE82a as part of the 100-F production reactor project.

Reference Wa79 indicates that "all long-lived (half-lives greater than 30 yr) radioactive materials and transuranics in excess of unrestricted release limits" will be removed to approved off-site disposal facilities and the remainder will be left on site, under barriers to prevent plant and animal intrusion. Reference DOE82a indicates that the waste will be disposed somewhere on the Hanford Site.

3.3.3.5 Characterization of the Wastes

Reference DOE82a provides project-by-project estimates of volumes of low-level and transuranic wastes to be generated by the SFMP. Estimates are not available for all projects. As pointed out earlier, the Monticello, Utah uranium mill accounts for 73 percent of the SFMP wastes estimated to date. A description of uranium mill and tailings wastes is found in Section 3.3.1.5 of this document and in Be82a. Specific sources of the TRU wastes are more diverse.

Tables 3-17 through 3-20 summarize estimates of SFMP wastes from DOE82a. The estimates are available in the four categories--soil, rubble, metal and miscellaneous--shown in the tables. The tables also indicate current estimates of the period during which the waste will be generated and anticipated sites for its disposal.

Disposal sites and waste generation dates are not shown in Table 3-19

TABLE 3-17

ESTIMATES OF LOW-LEVEL WASTES FROM SFMP COMMERCIAL PROGRAM

Source: DOE82a

Field Office and Project	Project Site	Disposal Site	Scheduled Generation Period	Waste Form and Volume			
				Soil (m^3)	Rubble (m^3)	Metal (m^3)	Misc. (m^3)
Albuquerque							
Mound ANSPD Areas	Mound	INEL	1981-1988	100	600	450	300
LAPRE II Vessel	LANL	LANL	TBD	--	--	--	--
TA-2 Water Boiler Reactor	LANL	LANL	1984-1988	100	200	100	115
UHTREX	LANL	LANL	1986-1987	0	50	30	35
Chicago							
Building 350 (Pu Gloveboxes)	ANL	INEL	1981-1982	0	20	50	20
Pu Fuel Fabrication Facility	W-ARD	HAN	1983	0	20	70	60
ANL-East Surplus Facilities	ANL	INEL	1985-1987	--	--	--	--
Juggernaut Reactor	ANL	INEL	1987-1988	0	25	50	40
Experimental BWR	ANL	INEL	1987-1991	0	50	50	15
Idaho							
Monticello Site	Monticello	TBD	TBD	1.13×10^6	0	0	0
SPERT III Ancillary Facilities	INEL	INEL	TBD	--	--	--	--
SPERT II Ancillary Facilities	INEL	INEL	TBD	--	--	--	--
SPERT I Ancillary Facilities	INEL	INEL	TBD	--	--	--	--
SPERT I Test Facility	INEL	INEL	TBD	0	10	10	10
SPERT IV Ancillary Facilities	INEL	INEL	TBD	--	--	--	--
Boiling Water Reactor Exper. V	INEL	INEL	TBD	100	400	400	500
Nevada							
Nuclear Rocket Development Sta.	NTS	NTS	1982-1983	0	0	0	45

TABLE 3-17 (CONT)

Field Office and Project	Project Site	Disposal Site	Scheduled Generation Period	Waste Form and Volume: Soil (m^3)	Rubble (m^3)	Metal (m^3)	Misc. (m^3)
Oak Ridge							
CEER Mayaguez	CEER	TBD	1982	0	20	20	20
Niagara Falls Storage Site	NF	TBD	TBD	75,000	15,000	0	10,000
Weldon Spring Site	WS	TBD	TBD	150,000	35,000	0	30,000
Molten Salt Reactor Experiment	ORNL	ORNL	1985-1990	30	100	50	50
Low Intensity Test Reactor	ORNL	ORNL	TBD	--	--	--	--
Reactor Experimental Facilities	ORNL	ORNL	TBD	--	--	--	--
Radioactive Process & Waste Fac.	ORNL	ORNL	TBD	--	--	--	--
Homogeneous Reactor Exper. No. 2	ORNL	ORNL	TBD	--	--	--	--
Waste Tanks	ORNL	ORNL	TBD	--	--	--	--
Richland							
Shippingport Atomic Power Station	SHPRT	HAN	1985-1988	0	5,000	5,000	5,400
San Francisco							
Sodium Reactor Experiment	SSFL	HAN	1981-1982	0	0	0	740
Advanced Fuels Laboratory	Vallecitos	HAN	1981-1982	0	0	0	0
Nuclear Material Dev. Facility	SSFL	HAN	1984-1986	--	--	--	--
SNAP 8 Test Facility	SSFL	HAN	1986-1988	0	0	0	770
Nuclear Dev. Test Facility	SSFL	HAN	1987-1989	0	0	0	770
Radioactive Mat. Disposal Fac.	SSFL	HAN	1984-1986	200	0	100	130
Interim Storage Facility	SSFL	HAN	1984	--	--	--	--
UC-Davis Waste Retention System	UC-Davis	HAN	1988	0	70	50	100
Savannah River							
Heavy Water Comp. Test Reactor	SRP	SRP	1987-1991	0	0	0	45
			Totals	1.36×10^6	56,600	6,430	49,200

Grand Total: $1.47\times10^6 m^3$

TABLE 3-18

ESTIMATES OF LOW-LEVEL WASTES FROM SFMP DEFENSE PROGRAM

Source: DOE82a

Field Office and Project	Project Site	Disposal Site	Scheduled Generation Period	Waste Form and Volume			
				Soil (m^3)	Rubble (m^3)	Metal (m^3)	Misc. (m^3)
Albuquerque							
SM Building	Mound	INEL	1983-1990	100	2,000	4,000	1,300
Sanitary Disposal Facility	Mound	INEL	1988-1990	100	100	100	100
Chicago							
New Brunswick Laboratory	NBL	NTS	1983-TBD	3,200	200	60	60
Idaho							
Liquid Waste Evaporator (PM-2A)	INEL	INEL	1982	20	0	0	10
Surplus CPP Facilities	INEL	INEL	1982-1988	400	200	200	350
Materials Test Reactor (MTR)	INEL	INEL	1983-1988	100	400	300	400
TAN-TECH Support Facilities	INEL	INEL	1988-1992	2,000	500	500	1,000
Heat Transfer Reactor Experiment	INEL	INEL	1987-1989	0	50	50	20
Army Reentry Vehicle Facility	INEL	INEL	1987	400	50	10	40
Initial Engine Test Facility	INEL	INEL	1987-1992	100	300	300	410
ARA I and II	INEL	INEL	1988-1990	300	100	100	200
ARA III and Leach Pond	INEL	INEL	1989-1991	50	0	0	20
ARA IV	INEL	INEL	1989-1991	0	0	0	60
MTR 756 Leach Pond	INEL	INEL	1991	--	--	--	--
Oak Ridge							
ILW Transfer Line	ORNL	ORNL	1982-1983	--	--	--	--
Curium Facility	ORNL	ORNL	1981-1984	--	--	--	--
Metal Recovery Facility	ORNL	ORNL	1984-1988	--	--	--	--
Fission Products Dev. Lab.	ORNL	ORNL	1985-1988	50	50	100	100
Waste Holding Basin (3513)	ORNL	ORNL	TBD	--	--	--	--
Old Hydrofracture Facility	ORNL	ORNL	1989-1990	--	--	--	--
Gunite Tanks	ORNL	ORNL	1989	--	--	--	--
Graphite Reactor	ORNL	ORNL	1990-1993	500	500	1,000	850

TABLE 3-18 (CONT)

Field Office and Project	Project Site	Disposal Site	Scheduled Generation Period	Waste Form and Volume Soil (m^3)	Rubble (m^3)	Metal (m^3)	Misc. (m^3)
Richland							
108-F Biological Laboratory	HAN	HAN	1983	0	50	100	100
100-F Production Reactor	HAN	HAN	1983-1988	1,000	3,000	4,000	4,650
Strontium Semiworks	HAN	HAN	1984-1988	0	1,000	2,000	2,100
100-H Production Reactor	HAN	HAN	1987-1989	1,000	3,000	4,000	4,650
233-S Pu Concentration Facility	HAN	HAN	1987-1989	0	100	250	390
Redox Processing Plant	HAN	HAN	1987-1993	0	0	2,000	2,000
216-Z-9 Crib	HAN	HAN	1987	0	0	0	60
Gable Mountain Storage Vaults	HAN	HAN	1988	0	170	0	0
100-D/DR Production Reactors	HAN	HAN	1989-1993	1,000	5,000	6,000	6,000
Z Plant Ground Disposal Facility	HAN	HAN	1991-1993	--	--	--	--
Redox Ground Disposal Facilities	HAN	HAN	1990-1991	--	--	--	--
T Plant Reprocessing Facilities	HAN	HAN	1989-1993	--	--	--	--
216-T Ground Disposal Facilities	HAN	HAN	1991	--	--	--	--
200-E Ground Disposal Facilities	HAN	HAN	1991-1994	--	--	--	--
U Plant Reprocessing Facilities	HAN	HAN	1992-1996	--	--	--	--
216-B Ground Disposal Facilities	HAN	HAN	1993-1995	--	--	--	--
Z Plant Reprocessing Facilities	HAN	HAN	1993-1995	--	--	--	--
Metal & Fuel Storage Basins	HAN	HAN	1995	--	--	--	--
Cesium Loadout Facilities	HAN	HAN	1994-1997	0	0	50	100
300 Area Waste Facilities	HAN	HAN	1994-1995	--	--	--	--
200 Area Peripheral Waste Fac.	HAN	HAN	1995-1997	--	--	--	--
Purex Ground Disposal Facilities	HAN	HAN	1995	--	--	--	--
T Plant Ground Disposal Fac.	HAN	HAN	1996	--	--	--	--
B & C Crib & Trench Field	HAN	HAN	1996-1997	--	--	--	--
B Plant Ground Disposal Fac.	HAN	HAN	1997	--	--	--	--
200 W Misc. Ground Disposal Fac.	HAN	HAN	1997	--	--	--	--
U Plant Ground Disposal Fac.	HAN	HAN	1996-1999	--	--	--	--
244-B Concentration Building	HAN	HAN	1996-1999	0	150	150	150
216-A Ground Disposal Fac.	HAN	HAN	1997-1998	--	--	--	--
Silica Gel Bldg. & Sample House	HAN	HAN	1997-1998	0	0	0	20
Misc. Ground Disposal Facilities	HAN	HAN	1997-1999	0	0	0	120
Schenectady Naval Reactors							
Separations Process Research Unit	KAPL	TBD	1990-1994	400	800	1,200	400
			Totals	10,700	17,700	26,500	25,500

Grand Total: 80,600m^3

TABLE 3-19

ESTIMATES OF TRANSURANIC WASTES FROM SFMP COMMERCIAL PROGRAM

Source: DOE82a

		Waste Form and Volume			
Field Office and Project	Project Site	Soil (m^3)	Rubble (m^3)	Metal (m^3)	Misc. (m^3)
Albuquerque					
Mound ANSPD Areas	Mound	100	200	300	430
LAPRE II Vessel	LANL	0	0	0	3
TA-2 Water Boiler Reactor	LANL	0	0	0	0
UHTREX	LANL	0	0	0	0
Chicago					
Building 350 (Pu Gloveboxes)	ANL	0	0	60	60
Pu Fuel Fabrication Facility	W-ARD	0	0	90	80
Juggernaut Reactor	ANL	0	0	0	0
Experimental BWR	ANL	0	0	0	0
Idaho					
Monticello Site	Monticello	0	0	0	0
SPERT III Ancillary Facilities	INEL	0	0	0	0
SPERT II Ancillary Facilities	INEL	0	0	0	0
SPERT I Ancillary Facilities	INEL	0	0	0	0
SPERT I Test Facility	INEL	0	0	0	0
SPERT IV Ancillary Facilities	INEL	0	0	0	0
Boiling Water Reactor Exper. V	INEL	0	0	0	0
Nevada					
Nuclear Rocket Development Sta.	NTS	0	0	0	0
Oak Ridge					
CEER Mayaguez	CEER	0	3	0	0
Niagara Falls Storage Site	NF	0	0	0	0
Weldon Spring Site	WS	0	0	0	0
Molten Salt Reactor Experiment	ORNL	0	0	0	0
Reactor Experimental Facilities	ORNL	0	0	0	0
San Francisco					
Sodium Reactor Experiment	SSFL	0	0	0	0
Advanced Fuels Laboratory	Vallecitos	50	100	350	150
UC-Davis Waste Retention System	UC-Davis	0	0	0	0
Savannah River					
Heavy Water Comp. Test Reactor	SRP	0	0	0	3
	Totals	150	303	800	726

Grand Total: $1{,}980 m^3$

TABLE 3-20

ESTIMATES OF TRANSURANIC WASTES FROM SFMP DEFENSE PROGRAM

Source: DOE82a

		Waste Form and Volume			
Field Office and Project	**Project Site**	**Soil (m^3)**	**Rubble (m^3)**	**Metal (m^3)**	**Misc. (m^3)**
Albuquerque					
SM Building	Mound	0	20	70	70
Sanitary Disposal Facility	Mound	0	0	0	15
Chicago					
New Brunswick Laboratory	NBL	0	0	0	0
Idaho					
Liquid Waste Evaporator (PM-2A)	INEL	0	0	0	0
Surplus CPP Facilities	INEL	0	0	0	45
TAN-TECH Support Facilities	INEL	0	0	0	0
Heat Transfer Reactor Experiment	INEL	0	0	0	0
Army Reentry Vehicle Facility	INEL	0	0	0	0
Initial Engine Test Facility	INEL	0	0	0	0
ARA I and II	INEL	0	0	0	0
ARA III and Leach Pond	INEL	0	0	0	0
ARA IV	INEL	0	0	0	0
Oak Ridge					
Metal Recovery Facility	ORNL	0	0	0	15
Fission Product Dev. Lab.	ORNL	0	0	0	0
Old Hydrofracture Facility	ORNL	0	0	0	0
Graphite Reactor	ORNL	0	0	0	0
Richland					
100-F Production Reactor	HAN	0	0	0	1,100*
Strontium Semiworks	HAN	40	40	60	60
100-H Production Reactor	HAN	0	0	0	1,100
233-S Pu Concentration Facility	HAN	10	40	70	90
Redox Processing Plant	HAN	250	250	700	500
Gable Mountain Storage Vaults	HAN	0	0	0	0
100-D/DR Production Reactors	HAN	0	0	0	2,200
Cesium Loadout Facilities	HAN	0	0	20	20
244-B Concentration Building	HAN	20	40	10	15
Silica Gel Bldg. & Sample House	HAN	0	0	0	10
Misc. Ground Disposal Facilities	HAN	0	0	0	30
	Totals	320	390	930	5,270

Grand Total: 6,910m^3

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* Assumes that the reactor block is classified as TRU waste due to Co-60 and C-14 content.

and 3-20 because they are the same as shown in Tables 3-17 and 3-18. Also, projects for which estimates of TRU waste volumes are not currently available are omitted from Tables 3-19 and 3-20.

The general nature of the low-level wastes can be determined by noting that almost 88 percent of the waste is soil--primarily from the Monticello, Niagara Falls and Weldon Spring sites. These wastes are primarily residues from processing uranium and thorium and their ores. They contain uranium, thorium and radium at concentrations up to those found in the ores (i.e., perhaps as high as 1,000 or 2,000 pCi/g; therefore not at transuranic (10,000 pCi/g) levels.

Similar conclusions about the nature of the transuranic wastes cannot be immediately drawn from Tables 3-19 and 3-20 because 67 percent of the waste is in the miscellaneous category. However, it can be noted that 73 percent of the miscellaneous TRU waste and, therefore, about half of all the TRU waste comes from 3 reactors--the 100-F, 100-H and 100-D/DR plutonium production reactors at Hanford.

3.3.3.6 Residual Materials

It is the intent of the SFMP to salvage as much material as possible during D&D. At the New Brunswick site the D&D contract provided incentives to the contractor to maximize salvage of clean materials. Approximately 7,800 ft^3 of waste was generated, compared to 46,000 ft^3 of clean materials and scrap. No estimates are available for salvage from future SFMP projects.*

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* Personal communication, David Doerge, United Nuclear Industries, Inc., April 22, 1982.

3.3.4 The Grand Junction Remedial Action Program (GJRAP)

The following history of GJRAP is taken largely from DOE81a. Between 1952 and 1966, several hundred thousand tons of uranium mill tailings were removed from the Climax Uranium Company's mill tailings pile in Grand Junction, Colorado, for use in construction projects. In 1966 the Colorado Department of Public Health and the U.S. Public Health Service became officially cognizant of this practice and ordered the mill to stop releasing the tailings. Investigations of their use as a construction-related material were initiated, and early in 1970 the U.S. Surgeon General provided guidelines for determining the need for corrective action at the many locations where the tailings had been used (PHS70).

In 1972, Congress passed Public Law 92-314 (later amended by Public Law 95-236) to provide authority and funding for a cooperative state-federal program to perform remedial actions on contaminated structures in Grand Junction. This program has evolved into the GJRAP.

The GJRAP oversees corrective action for those structures where gamma radiation levels and/or radon daughter concentrations exceed the program criteria (10CFR 712), which are based on the Surgeon General's guidelines. It is estimated that approximately 800 structures require remedial action (DOE79).

From 1973 through calendar year 1980, rehabilitation was started or completed on 394 structures, generating about 45,000 m^3 of waste. The additional volume of waste that will be generated is expected to be less than that which has already been produced. The current scheduled completion date for the GJRAP is the end of calendar year 1986.

The Surgeon General's standards for remedial action at Grand Junction specify limits on radon daughter working levels in indoor air rather than radium concenterations in the ground near or under a structure. Therefore, there is a weaker linkage between these standards and amounts of waste generated by GJRAP than if maximum permissible radium concentrations in the soil were specified. A variety of methods have been tried to reduce levels of radon daughters inside structures at which Climax tailings were used. These include epoxy sealants, natural and forced ventilation and electrostatic precipitation air cleaners for removing radon daughters. The methods were often employed where removal of the tailings would involve excessive expense. However, the alternative methods have not always proven satisfactory and tailings removal remains the preferred technique (DOE79).

The waste generated from GJRAP is almost entirely tailings and tailings mixed with soil. It has been placed in a state-owned tailings repository adjacent to the Climax tailings pile.

In terms of the amount and radioactivity of low-level waste to be disposed GJRAP is relatively insignificant compared to the Grand Junction site covered by UMTRAP. If the 45,000 m^3 of waste produced by GJRAP by 1980 is conservatively assumed to be half of all the GJRAP ultimately generated, it is less than 10 percent of the volume of mill tailings at the Grand Junction pile (see Table 3-4) and less than 5 percent of the estimated volume of tailings and contaminated soil underneath (see Table 3-6). Furthermore, because of mixing with clean soil, any GJRAP waste will probably have smaller average concentrations of radionuclides than the tailings at the Grand Junction UMTRAP site. Therefore, no additional details concerning waste from GJRAP are provided here.

3.3.5 Currently Active DOE Facilities

DOE facilities that are currently in use are not included by definition in any of the remedial action programs described in the preceding sections. However, there are activities at some of the active facilities that are surplus and are being handled under the SFMP. In some instances surplus activities are mentioned in the characterization of the active sites. The intent is to ensure that all activities are noted.

Many of the contaminated facilities now in use by DOE are associated with the National Laboratories. In compiling this brief description of current DOE facilities that may eventually require D&D, it has been assumed that facilities that are currently generating radioactive waste will be contaminated to some extent. Lists of facilities generating radioactive waste are therefore the basis for descriptions of current DOE facilities that will eventually require D&D.

The active facilities have been divided into five groups as shown in Table 3-21. The groups are somewhat subjective. However, the facilities classified as laboratories have more diversified programs than those in the other groups. The latter generally perform more specialized functions (e.g., Rocky Flats is primarily dedicated to plutonium fabrication).

The various activities conducted at a given lab complex have all been associated with the complex. For example, the Y-12 and gaseous diffusion plants at Oak Ridge are associated with ORNL. Fuel reprocessing and the production reactors are all associated with the Savannah River facilities.

TABLE 3-21

ACTIVE DOE FACILITIES

Diversified Laboratories

Idaho National Engineering Laboratory, Idaho Falls, Id.
Argonne National Laboratory, Chicago, Ill.
Brookhaven National Laboratory, Upton, N.Y.
Hanford Reservation, Richland, Wash.
Los Alamos National Laboratory, Los Alamos, N.M.
Lawrence Livermore National Laboratory, Livermore, Ca.
Oak Ridge National Laboratory, Oak Ridge, Tenn.
Sandia National Laboratories, Albuquerque, N.M.
Savannah River, S.C.

Ames Laboratory, Ames, Iowa
Mound Facility, Miamisburg, Ohio
Knolls Atomic Power Laboratory, Nishayuna, N.Y. (3 sites)
Bettis Atomic Power Laboratory, Pittsburg, Pa. (2 sites)
Lawrence Berkeley Laboratory, Berkeley, Ca.

Nuclear Materials Production Facility	Primary Program
Ashtabula, Ohio	U Extrusion & Billet Formation
Fernald, Ohio	Produce Purified U Compound
Paducah, Ky.	U Enrichment
Portsmouth, Ohio	U Enrichment

Weapons, Production and Testing

Kansas City, Kansas	Non-nuclear material
Nevada Test Site, Nevada	Nuclear testing
Other Test Sites	Nuclear testing
Pantex, Texas	Weapons assembly
Pinellas, Florida	Neutron Generators
Rocky Flats, Colorado	Pu fab. and chemistry

Physical Research

Bates Linear Accel., Cambridge, Massachusetts	Nuclear and Atomic Physics
Fermi Nat. Accelerator Lab, Illinois	Nuclear and Atomic Physics
Notre Dame Rad. Lab, Indiana	Physical Chemistry
Stanford Linear Accel, California	Nuclear Physics

Other

New Brunswick Laboratory, Chicago, Illinois	Nuclear Safeguards
Princeton Plasma Physics Lab, New Jersey	Fusion

Using this terminology, reference is made to the Savannah River facilities (total), not just the plant or lab.

The other facilities are broken into categories based on their primary function. Activities for the national laboratories are not relisted under these categories. For example, weapons work at Y-12 Oak Ridge, Savannah River or Mound is not included under the Weapons Production and Testing listing.

Several laboratories or facilities and a number of activities at some of the facilities are not pertinent to this section, but are included for completeness. Gaseous diffusion plants (uranium enrichment) are present at ORNL, Paducah, and Portsmouth. Although these are government facilities, they are part of the uranium fuel cycle and are included in that report. Accelerators, including the Fermi Lab accelerator, are covered in Chapter 10 of this report.

Fuel reprocessing has been conducted on a process scale at three of the major labs. Estimates of the D&D wastes from reprocessing are developed in Appendix B and used for the pertinent facilities.

Many of the DOE facilities were founded to support the U.S. effort to develop nuclear weapons. Many of them still have considerable involvement in the weapons program; however, most have diversified into other program areas.

The radioactive waste disposal facilities listed include major contaminated soil cribs and columns. There are also many minor areas of soil contamination around pipe breaks or spills, etc., which may require future D&D activities.

3.3.5.1 Status

It is difficult to project a lifetime for these facilities. Many of them are presently 30 to 40 years old. The lifetime is more a function of national needs and national programs than how long equipment or buildings will last.

Most of the labs are a complex of basic activities or individual facilities that can support numerous programs. Activities at the laboratories range from plutonium production reactors and fuel reprocessing to radiochemistry laboratories. Buildings and equipment are modified to meet program requirements. Even specific reactor facilities are often modified to meet new program requirements.

A nominal facility lifetime of 40 years is postulated. This is based on the present surplus status of many of the individual facilities and the age of the existing facilities. The variance around the nominal lifetime is estimated to be about plus or minus 20 years. One of the most important factors in the lifetime is the flexibility of the facility for meeting changing program needs.

The projected lifetime for specific facilities or activities within the facility (reactors, etc) is closer to 20 to 30 years. Again, this will depend on the duration of a specific program and the flexibility of the activity to adapt to changing program needs.

3.3.5.2 Representative Facility

A representative facility has not been developed for the active DOE facilities because of their diversity of functions. However, reference facilities have been used to provide additional information on the range of activities at the major labs and to obtain estimates of D&D wastes. Furthermore, a more detailed discussion is presented for the Idaho National Engineering Laboratory (INEL) than for the other laboratories. Although the activities of the other labs differ from those of INEL, the range of activities at INEL helps characterize the diverse programs. Reference reactor and fuel reprocessing facilities were developed to provide a tool for estimating waste volumes and activities. These reference facilities are described in Appendices A and B. Waste estimates for reference fuel fabrication plants and uranium conversion plants (E180, E181) were also used to estimate D&D wastes from some activities. Although accelerators are identified in the lists of activities at the various DOE facilities, the assessment of all government accelerators is contained in Chapter 10.

3.3.5.3 Existing Contamination

The individual active DOE facilities are described in the following paragraphs. Most of the sites have national defense related activites. Therefore, in many cases there is very little unclassified information available. Furthermore, in most cases there are no plans for D&D of the active facilities and it is difficult to make estimates of the wastes resulting from D&D.

This section presents a brief characterization of each site or facility, a list of identifiable activities, and identifiable waste volumes. The lists of DOE facilities and basic information are derived from DOE77b, DOE79c, ERDA77e, ERDA77g and NRC79 and personal communications. There is some question as to whether several sites are actually DOE sites, and in some cases whether activities should be listed under the SFMP or Active Sites. The decision was made to list sites twice in those cases.

Idaho National Engineering Laboratory - The INEL, formerly the National Reactor Testing Station, was established in 1949 by the Atomic Energy Commission. INEL was established as an area where various types of nuclear reactors, support plants, and associated equipment could be built, tested, and operated with maximum safety. The site covers an area of about 2,300 km^2 and has facilities with about 0.16 km^2 of space. A total of 51 reactors and critical facilities have been built at INEL, 15 of which are still operable. These include reactors for the following programs: aircraft propulsion, naval propulsion, fast breeder development, light water safety tests, moderator and coolant development, materials testing, portable military power plants and miscellaneous research. A decontamination and decommissioning program is underway to ensure disposal of the retired facilities and equipment in a safe manner (ERDA77, Me78).

Other INEL facilities include the Idaho Chemical Processing Plant (ICPP), radioactive waste management complex (RWMC) for burying and storing various forms of solid radioactive waste, and the first plant-scale facility for continuous solidification of high-level waste. The ICPP processes spent fuel from government owned reactors, including Navy and ship reactors. It has also been used for developing improved fuel reprocessing and waste management methods and for storing fuel from various government reactors. The uranium it recovers from enriched uranium fuels is used as feed material for the Savannah River production reactors (DOE80g).

Most of the original reactor buildings have been modified over the years to accept follow-on reactor experiments. Therefore, rather than 34 empty excess reactor buildings, there are only about 14 candidates for the SFMP (ERDA77, NRC79).

Prototypes of three of the world's major power reactor concepts (i.e., pressurized water, boiling water, and liquid metal cooled fast breeder) were built and operated at INEL. The first prototypes of a nuclear submarine reactor and a Navy surface ship reactor were also built and operated at the INEL.

At present, the facilities and expertise at the INEL are being used to further high priority energy R&D programs including: water reactor safety testing; materials and fuel development for water-cooled reactors; naval propulsion reactors; reactor fuels processing and waste management; materials and fuels testing for the liquid metal cooled breeder reactor; and geothermal electrical and space heating applications.

INEL D&D programs have included decommissioning of two reactor complexes. One of the largest D&D efforts undertaken at the INEL was in connection with the SL-1 accident in 1961. Following that accident, the entire facility, including the reactor and its building, was removed and buried. The EBR-I complex has also been decommissioned following decontamination to levels sufficient for turning that facility over to the National Park Service as a museum and visitor's center (ERDA77).

Airborne radioactive effluents are currently discharged to the atmosphere through stacks from the reactor facilities, the ICPP and some support facilities. The annual average radioactivity released to the atmosphere from 1967 to 1977 was about 150,000 curies, of which 85,000 curies was krypton-85, 2500 curies was tritium, and the remainder was primarily short-lived noble gases. Radioactivity in the air at the INEL boundaries is well below the concentration guides (DOE81d) for exposure of the general population (ERDA77g).

Liquid effluents containing low levels of radioactivity are discharged to ponds and wells. The annual average activity released to the lithosphere from 1967 to 1977 was about 2500 curies of which 600 curies was tritium. However, discharges directly to the lithosphere are being phased out.

High-level liquid radioactive wastes generated at ICPP are calcined to a solid form for safer interim storage. Through 1979, a total of 14,260 m^3 of high-level waste had been processed into 1703 m^3 of calcine containing 61.6 MCi of activity. A total of 7,210 m^3 of high-level liquid waste is currently stored in stainless steel tanks contained in underground concrete vaults awaiting calcination.

Approximately 40,000 m^3 of solid transuranic waste (principally plutonium-239) generated at the INEL and other DOE facilities, have been stored at the INEL through 1979. Initially in the 1950s and 1960s, transuranic wastes were packaged and buried for disposal. However, since November 1970, newly received TRU wastes have been packaged in sealed containers, stored above ground on asphalt pads, and covered in such a manner that they are readily retrievable for at least 20 years. Furthermore, former wastes classified as TRU are being removed from the burial ground.

The storage and disposal sites are monitored routinely to ensure that radioactivity is not migrating at unacceptable levels into the environment (ERDA77, NRC79).

The INEL encompasses 2300 km^2 (572,000 acres). The site is a desert plain at an average elevation of approximately 5000 feet above sea level. The plain extends across southern Idaho and is characterized by soil of relatively shallow depths underlain by basalt rock.

Radiation related activities are located well within the boundaries of the INEL. The closest major population center is Idaho Falls, 50km from the eastern boundary of INEL. The population living within a 80km radius of INEL is approximately 70,000. Land uses in the surrounding area include urban, industrial, irrigated farming, and dry land farming. In addition, a small area of the INEL is used to graze sheep and cattle in the spring and fall.

The discharge of radioactivity to the atmosphere from stacks during routine operations is the most important local source of man-made radionuclides found in the on-site or off-site environs. The radioactive particulate materials released result in small exposures to a number of individuals and small areas of contaminated soil around the facility. General population exposures occur as the result of noble gases and tritium. The calculated 80km radius annual population dose is 1.2 man-rem, which is only 0.008 percent of that from natural background (16,000 man-rem/year).

An additional small environmental effect results from the routine release of liquids containing low levels of radioactivity into ponds or wells. The USGS regularly monitors the aquifer to determine the extent of released radionuclides. Tritium, strontium-90, plutonium, and iodine-129 have been detected in groundwater at various distances from the discharge points. Tritium from INEL has not been detected farther than about 8 km from the release point, which is 5.6 km inside the nearest site boundary. Strontium has not been detected at distances greater than about 3 km from the point of release, or about 10 km inside the nearest site boundary. Plutonium has been detected up to only 70 m from the disposal well and iodine-129 has been detected 580 km from the well.

A postulated range of nonroutine incidents or accidents that might occur, based on present facility design and operation, would include tank leaks, process line leaks, accidental airborne releases, major facility filter failures, on-site shipment accidents, range fires, solid waste disposal site fires, and accidents due to natural forces. Such accidents would lead to a certain amount of contamination spread. However, environmental effects have been calculated to be small.

In 1969, a controversy arose over the safety of burial at INEL of transuranic-contaminated solid waste from the Rocky Flats Plant. After the controversy, the DOE planned that when a Federal repository was available, such waste would be transferred to it from the INEL. Moreover, it was decided that additional such materials received at INEL would be stored in a readily retrievable mode. The plan was based on the belief that transferral to an underground repository in salt appeared to be the best method for attaining very long-term isolation of these wastes.

Currently four major contractors operate facilities at INEL:

- EG&G Idaho, Inc. operates the Test Reactor Area (TRA), Test Area North (TAN), Loss-of-Fluid Test (LOFT), Power Burst Facility (PBF), Auxiliary Reactor Area (ARA), INEL Radioactive Waste Management Complex (RWMC), and Central Facilities Area (CFA). The operations at CFA provide support services for outlying INEL operational areas including transportation, warehouse, cafeteria, laundry, purchasing, and other services.
- Exxon Nuclear Idaho Company, Inc. (ENICO) operates the Idaho Chemical Processing Plant (ICPP).
- Argonne National Laboratory (ANL) operates Argonne National Laboratory West (ANL-W) which includes the Experimental Breeder Reactor No. 2 (EBR-II) and other associated facilities.
- Westinghouse Electric Corporation (WEC) operates the Naval Reactor Facility (NRF).

These facilities support six major programs. One program provides test irradiation services from the two operating high-flux test reactors: the Engineering Test Reactor (ETR) and the Advanced Test Reactor (ATR) at TRA. A second major program involves light water cooled reactor safety testing and research. ICPP recovers uranium from a variety of spent reactor fuels and conducts and demonstrates technology for the treatment of high-level radioactive liquid waste. An important and expanding segment of INEL responsibilities consists of assignments for furthering DOE's Liquid-Metal Fast-Breeder Reactor (LMFBR) program. This research is being conducted principally at the Argonne National Laboratory West (ANL-W). NRF is a training and experimental facility for U.S. Navy nuclear programs. An additional area of program support provided by the INEL is in the area of alternate energy sources, including low-head hydro plants and geothermal utilization.

All of the above INEL operations produce various quantities of radioactive and nonradioactive waste effluents. The processes by which the radioactive wastes are produced and controlled at all of the INEL reactors are similar (ICPP processes differ because it is a fuel reprocessing facility). The major radioactive contaminants from reactor operations are fission and activation products. The fission process within the reactor produces the fission products. The reactor fuel and the fission products formed during nuclear operations are contained within sealed metal sheaths called fuel elements. Although strenuous precautions are taken to contain all of the fission products within the fuel elements, 100 percent containment is not possible. For example, some fission products migrate through the fuel element cladding and become entrained in the primary coolant fluid. Further, the radionuclides that result from activation of reactor internals and primary coolant impurities also are present in the primary coolant stream. Radioactive gases are removed from the liquid in degassing vessels and routed to waste gas systems prior to release from high-rise stacks. Most INEL reactors use closed-cycle and water-cooled systems. The closed-cycle systems (called the "primary coolant systems") contain most of the radioactivity and are not discharged to waste systems until the reactor is shut down and the primary system is drained. Additional effluent from sample and purge streams, both of which contain small quantities of radioactivity, are discharged continuously to waste systems during reactor operation. In addition to short-lived isotopes which decay rapidly, minor quantities of long-lived fission and activation products (e.g., H-3, Cr-51, Co-60, Sr-90, Nb-95, and Zr-93) are in the waste stream.

Expended fuel elements, which contain most of the fission products and unfissioned uranium, are removed from the reactor and transferred to the ICPP in shielded containers for recovery of the uranium. At the ICPP the fuel elements are subjected to chemical procedures. First, they are dissolved by acids. The uranium in the acid solution then is chemically separated from the other materials. The high-level radioactive waste, containing the fission products and transuranics is then routed temporarily to underground storage tanks. Subsequently, it is solidified and stored as a calcined solid.

Facilities at the INEL are periodically reviewed and their ultimate status assessed by the DOE. As facilities become excess to current needs, they are shut down into a safe standby status and detailed D&D plans are prepared. Experience to date at the INEL with D&D indicates that most facilities can be cleaned up, demolished or removed sufficient to allow unrestricted use of their sites. Some areas, such as waste disposal sites, however, are considered permanent commitments of the area. Several INEL facilities are listed in the SFMP section (Section 3.3.3).

Under current concepts, complete D&D of all INEL facilities would still require restricting access to several remaining structures and burial grounds for a considerable period of time. The quantity of committed land, approximately 210 acres, would remain constant for about 300 years, because of the presence of Cs-137 and Sr-90. After about 300 years, the restricted area could be limited to about 60 acres containing TRU waste. A general summary of the committed land areas is given in Table 3-22.

TABLE 3-22

DEDICATED WASTE MANAGEMENT LANDS AT INEL

Description of Land		Approximate Area (acres)
Radioactive Waste Management Complex		
Subsurface Disposal Area (SDA)		88
Transuranic Storage Area (TSA)		58
SL-1 Burial Ground		4
ANL Radioactive Scrap and Waste Facility		5
ICPP Calcined Waste Storage Area		3
Seepage Basins/Evaporation Ponds		52
	Total	210

Table 3-23 presents a summary of information on the contamination of various plots of soil at INEL. The sites include dry wells, seepage pits, and accidental releases. Most of this information was taken from ERDA77b. The estimates are only approximate. Estimates of contamination are not available for all locations, and all sites, especially seepage and storage ponds, are not included.

Table 3-24 provides a summary of activities at INEL. This listing is based on ERDA77b, supplemented by DOE79c. Estimates of D&D wastes for most of the activites are based on the reference facilities in Appendix A. The estimates for the Idaho Chemical Processing Plant (ICPP) are based on a review of the plant in Appendix B. Estimates of contaminated soil are summarized separately in Table 3-23 and are not included in Table 3-24.

It must be recognized that although more detail is given for INEL than other DOE facilities, the list of activities is incomplete and the waste volumes are only general estimates. Furthermore, because of changes in the status of operations and difficulties in specifically identifying operations, some operations on the Surplus List (SFMP) may be included.

The estimated waste volume from D&D for all of the INEL actiities is 1.6×10^5 m^3 (Table 3-24), containing 2.2×10^6 curies of activity. These are at best order of magnitude estimates, and are probably under estimates because of the lack of information on many facilities. The estimates are based on leaving buried LLW in place, but retrieving the stored TRU waste and contaminated soil from accidents and liquid waste disposal activities. The stored HLW is not included.

TABLE 3-23

CONTAMINATED SOIL AT INEL

Location	Date	Area (m^2)	Volume (m^3)	Activity (Ci)
Test Reactor Area				
Retention Basin and Leach Ponds	Since 1952			
Hot Waste Storage Tank, Leach				
TAN-616, Adjoining Area		500	150[a]	
MTR-758 Seepage Pond		20,000	20,000[b]	150, Sr and Cs
MTR-712 Retention Basin				1000, Co-60
ARA and SPERT Reactors				
About 8 Leach Ponds				
SL-1 Burial Ground				
ICPP Processing Plant Area				
CPP-740 Shallow Dry Well Monitoring Manhole	About 1966			40, Sr and Cs
CPP-603 2 filter wash basins				2
Overflow of 1 of above basins			20	5, Sr and Cs
CPP-603 Filter Feed Line, Leak	1973		250	9, Sr and Cs
CPP-603 Septic Tank			20	1
CPP-603 Airborne Release	1958	20,000	1000[c]	100
ICPP Injection Well		30,000	10,000[a]	1
Calcining Facility, Line Leak			1000	100 Ru-106
Calcining Facility, Spill		100	30	3, Sr and Cs
CPP-604 Septic Tank			20	1
Tank Farm Const.		150	50[b]	1
CPP HLW Line			50	3,000, Sr, Cs,
Total (rounded off)			33,000	4,400

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[a] Assume contamination to a depth of 0.3m.
[b] Assume contamination to 1 meter (probably deeper).
[c] Assume top 5 cm is removed.

TABLE 3-24

IDAHO NATIONAL ENGINEERING LABORATORY SUMMARY

		D&D Waste	
Facility or Activity	Nuclides[e]	(m^3)	(Ci)
- Test Reactor Area			
Engineering Test Reactor	AP	5,000	410,000[a]
Adanced Test Reactor	AP	5,000	410,000[a]
Eng. Test Reactor, Crit. Facility R		10	1
Adv. Reactivity Meas. Facility R	AP	35	1,400
Coupled Fast Reactor Meas. Facility R	AP	500	41,000[d]
Adv. Test Reactor Critical Facility R		10	1
Material Test Reactor - Shut down		(SFMP)	
Support Facilities		(Included in above)	
Hot Cells and Fuel Storage			
Laboratories			
Leaching Pond (2×10^4 m^2)			
- Power Burst Facility	AP	5,000	41,000[d]
- Test Area North		Not known	
Loss of Fluid Test Facility (Former Aircraft Propulsion Area)	FP		
Hot Cells			
Support Facilities			
- Central Facilities Area			
Support Facilities			
Contaminated Laundry			
- Auxilary Reactor Area			
Former SL-1 (Destroyed)			
Hot Cells & Metallurgy Labs	FP, AP		
- Radioactive Waste Management Area Storage & Disposal of LLW & TRU	Co-58 & 60 Cs-137, Mn-54 Ni-59, Sr-90	Stabilize in Place	
Subsurface Disposal Area LLW, TRU before 1970. TRU is being removed			

TABLE 3-24 (CONT)

Facility or Activity	Nuclides[e]	D&D Waste	
		(m^3)	(Ci)
LL Transuranic Disposal Final burial; 10 nCi/g TRU			
Trans. Storage Area (TSA) Interim Storage TRU	Am-241, Pu-238, 239, 241	10^5	200,000
Decontam. Facilities			
- Idaho Chem. Processing Plant (ICPP)	FP, TRU		
Fuel Reprocessing & Waste Calcining	FP	5,700	14,000[f]
HLW Storage Facilities	FP, TRU	3,300	9,500[f]
- Argonne West (ANL-W)			
Exp. Breeder Reactor II	AP	5,000	410,000[a]
Zero Power Research Reactor	AP	10	1[c]
Transient Reactor Test Facility (TREAT)	AP	35	1,400[b]
Heat Fuel Exam. Facilities (HFEF-N&S)			
Irrad. Waste Storage Area			
Support and Lab. Facilities			
- Naval Reactor Facility (NRF)			
Three Prototype Reactors		7,000[g]	615,000[g]
Hot Fuel Examination Facilities			
Technical Support Buildings			
Rad. Effluent Leach Ponds			
Subtotal except TRU storage area		$3x10^4$	$2x10^6$
Total with TRU from storage area		$1.3x10^5$	$2.2x10^6$
Areas with contaminated soil (some on SFMP) from Table 3-23		$3.3x10^4$	$4.4x10^3$
Overall Total		$1.6x10^5$	$2.2x10^6$

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[a] Used reference test reactor.
[b] Used reference research reactor.
[c] Used reference mockup reactor/critical facility.
[d] Reduced reference facility by 0.1 for shorter operating times.
[e] FP, fission products; AP, activation products; TRU, transuranics
[f] From Appendix B
[g] Three reactors. Assume soil etc for 1 test reactor, waste from reactor materials for all three. Assume Ci inventory is one-half of the reference reactor due to shorter operating time.

The stored TRU waste accounts for almost the total volume and 10 percent of the curie content. If the stored TRU waste and contaminated soil are excluded, the subtotals are $3x10^4$ m^3 and $2x10^6$ Ci.

Argonne National Laboratory - Argonne National Laboratory's (ANL) principal program activities are reactor development, energy and environmental technology, and energy sciences and nuclear physics research. The primary laboratory is near Chicago, Illinois and ANL-West, a reactor laboratory, is at INEL in Idaho. ANL-West was included in the previous INEL section. ANL is operated by the University of Chicago and Argonne Universities Association. The Chicago Site covers an area of 7 km^2 and has 0.35 km^2 of building space.

The major facilities and estimates of associated D&D wastes are given in Table 3-25 (ERDA77g, DOE79c). The total identified D&D waste other than for accelerators is 90 m^3 and 2800 Ci (primarily activation products). The estimates, especially the volume, are probably low because of the lack of information on specific activities. However, ANL is not listed as a site where there is storage or disposal of waste (NRC79).

Brookhaven National Laboratory - Brookhaven National Laboratory (BNL), founded in 1947, is located on a 22 km^2 site at Upton, New York, about 60 miles east of New York City, near the geographical center of Long Island. The lab, operated by a consortium of universities, was established by the AEC to provide research facilities for the peaceful uses of nuclear energy, under the direction of the Chicago Operations Office.

The major facilities at the site are listed in Table 3-26. Available information on existing contamination and projected D&D wastes is given in

TABLE 3-25

ARGONNE NATIONAL LABORATORY SUMMARY

Facility or Activity	D&D Waste (m³)	D&D Waste (Ci)
JANUS Reactor, 0.2 Mw	35	1,400*
CP-5, 5Mw Research Reactor	35	1,400*
ZPR-6 Zero Power reactor	10	1
PR-9 Zero Power Reactor	10	1
Juggernaut Reactor (Surplus-SFMP)		
Experimental Boiling Water Rector (Surplus-SFMP)		
60" Cyclotron		
12.5-GeV Proton Accelerator		
9 MeV Tandem Van de Graaff		
Two Large Dynamitrons		
Several Particle Accelerators		
Pulsed Neutron Source with 500-MeV Proton Accelerator		
Extensive Animal Facilities		
Extensive Laboratories		
Large Alpha/Gamma Hot Cell		
Pu Glove Boxes		
Appendix 10 lists a total of 12 Accelerators		
Total (except for accelerators)	1,300	410,000

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* Based on the reference research reactor.

the table. The buildings have a floor space of about 0.27 km^2 (ERDA77g, DOE79c).

BNL is storing some low-level wastes on site in the Graphite Reactor waste treatment facilities. This waste, which originated with site activities, accounts for 100 m^3 of LLW (unspecified radionuclides). Furthermore, contaminated equipment from BNL reactors is held in storage trenches and shafts (NRC79).

Low-level waste from past laboratory activities was buried in the site landfill area. The present volume or curie quantity is not reported. However, data through 1973 showed about 3.4 Ci of activity (NRC79). Solid wastes, except for the previously mentioned equipment are apparently shipped off site. A site map from ERDA77g indicates the landfill area is over 0.1 km on a side or about 3 ha.

The 1976 environmental report indicated that the primary airborne release was tritium. Also, 62 pCi/l of strontium-90 in groundwater was observed from an inadvertant injection in 1960 and concentrations of 400 pCi/l of tritium in groundwater are reported in the waste management area (ERDA77g).

The estimates from Table 3-26 indicate 1300 m^3 of waste and 410,000 Ci of activity from D&D of the site, excepting the accelerators and LLW site.

Hanford Reservation - The Hanford Reservation (Hanford) is near Richland, Washington. It is owned by the DOE and covers an area of about 1500 km^2. The on-site buildings cover an area of about 0.1 km^2 (DOE79c). Hanford was developed for producing and processing plutonium for the

TABLE 3-26

BROOKHAVEN NATIONAL LABORATORY SUMMARY

Facility or Activity	Nuclides[c]	D&D Waste (m^3)	D&D Waste (Ci)
High Flux Beam Reactors, 40 Mw	FP, AP	1,100	410,000[a]
Medical Research Reactor, 3 Mw	AP	35	1,400[b]
Alt. Gradient Synchrotron, 35 GeV	AP		
Linac Accel, 200 MeV	AP		
Tandem Van de Graaff	AP		
60" Cyclotron	AP		
Research Van de Graaff	AP		
Vertical Accelerator	AP		
Chemistry Van de Graaff	AP		
(Appendix C lists a total of 10 accelerators)			
Laboratories			
Medical Research Center			
Biology Dept. (Field Ins & Source)	FP, AP, H-3		
Dept. Applied Science (Includes Hot Lab)	FP, AP, H-3		
Waste Treatment Center			
Chemistry Department			
LLW Storage			
Old Landfill - about 30,000 m^2	Sr-90, H-3, etc		
On-Site Storage		200	200
Old Equipment			
Total (except for accelerators)		1,300	410,000

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[a] Used reference test reactor.
[b] Used reference research reactor.
[c] FP, fission products; AP, activation products.

weapons program. Except for some cleanup work, this program is essentially finished. The chemical processing facility has been in standby condition since 1972 and the eight production reactors were shut down between 1964 and 1971. The only operating production reactor is the N-Dual Purpose Reactor, for plutonium production and production of electric power (ERDA75). Other activities at the site include the Fast Flux Test Facility, Laboratory Services (Battelle Pacific Northwest Laboratory), a pilot activity on the reprocessing and solidification of commercial fuel, and the solidification and encapsulation of cesium and strontium.

Both solids and liquids with low levels of activity have been disposed of in 370 separate locations in the 100, 200, and 300 areas using shallow land burial for solid wastes, and cribs, ponds, ditches, pits, trenches, french drains, and reserve wells for liquid wastes. All of the waste in these locations is predominantly defense related and has a total volume of 1.79×10^6 m^3 with a total activity of 1.65×10^6 curies. The buried low-level waste includes 1.6×10^4 m^3 of contaminated soil containing 3.1×10^4 Ci which were unplanned releases. Some of the 370 locations in the 200 area are still active and receiving waste; the others are inactive (NRC79, K179, K179a, RHO77, RHO78, RHO78a, RHO78b, ERDA75, RHO78e, DOE77a).

Through 1978, there were 20 unintentional releases of high-level waste from tanks into the soil beneath the storage tanks. Approximately 436,000 gallons have been lost. One release was more than 100,000 gallons and eight releases were between 10,000 and 100,000 gallons each. The remaining 11 releases have been less than 10,000 gallons each. After reviewing the data in references provided by DOE, NRC also found a number of instances where high-level waste was intentionally released to the ground. In some cases, the waste had been treated to reduce the fission product content, but 16 cribs (K179a) received first and second cycle supernate (first cycle wastes are considered HLW). These releases apparently occurred during a period (1953 to 1957) when plutonium was being produced and high-level waste storage tank capacity was not available (NRC79). The NRC has no estimate of how many gallons of high-level waste were discharged to the ground (NRC79). Hanford presenty has 156 tanks for high-level waste storage, of which 38 are in active service.

Transuranic wastes have been stored at the Hanford Reservation in the 200 area at five locations. The volume of TRU stored waste in the 200 area is 7.7×10^3 m^3. The activity is 1.03×10^5 curies. Waste is currently being added to the 200 area storage facilities (NRC79, K179, K179a, et al). HLW from fuel reprocessing for plutonium, along with any other designated waste, is stored at the Hanford site in the 200 area in various locations. These locations are the tank farms, the B plant and the Waste Encapsulation and Storage Facility. Each of those locations is described below:

- Tank Farms

  There are 15 tank farms (A, AX, AY, AZ, B, BX, BY, C, S, SX, SY, T, TX, TY and U) in the 200 area with a total of 156 tanks. Liquid waste (supernate and sludge) and solid waste (salt cake) are stored in the tanks. The volume of HLW located in the tank farms is 1.78×10^5 m^3, and the activity is 1.08×10^8 curies. Of the 156 tanks, 38 are in active liquid service and 118 are inactive.

- B Plant

  The B plant removes Sr-90 and Cs-137 from high-level radioactive waste produced from the processing of irradiated fuel from the Hanford reactors. The volume of Sr-90 and Cs-137 solutions held in storage at the B plant is 105 m^3, and the activity is $1.5x10^8$ curies.

- Waste Encapsulation and Storage Facility

  The Waste Encapsulation and Storage Facility (WESF) takes waste held in storage at the B plant and encapsulates the Sr-90 and and Cs-137 and stores the capsules. The number of capsules held in storage at the WESF is 400, and the activity is $3.1x10^7$ curies.

There are presently 13 underground tanks under construction at the Hanford Reservation. The current estimate is that no additional tanks will be needed until the year 2000. These tanks will be used to store high-level waste as generated or transferred from existing tanks. The tank farms have two working evaporators which process waste through evaporation.

Many of the facilities at Hanford are on the SFMP list (DOE82a). However, although eight of the production reactors are shut down there are only four reactors on the current draft list (See Section 3.3.3). Some facilities that were planned have been cancelled. Therefore, it is difficult to make a current list of "active" facilities.

The four production reactors (and associated facilities) on the SFMP list are the 100D, 100Dr, 100F, and 100H. It is assumed that the four other facilities are considered in a standby status.

There have been at least six fuel reprocessing plants at Hanford. Four of these, the Redox, T Plant, V Plant and Z Plant are on the SFMP list. Ground disposal facilities for the B plant and Purex plant are on the list, but the plants are not (DOE82a). The B Plant was built as a reprocessing plant (Bismuth Phosphate Process). Later it was converted to a waste fractionation plant to remove Sr-90 and Cs-137 from wastes. The Purex facility is apparently being brought back on line by Rockwell. These facilities are discussed in Appendix B.

The active facilities at Hanford are listed in Table 3-27. Facilities for storing TRU waste, as well as cribs and seepage pits associated with some of the reprocessing are also listed. However, the cribs, etc, are excluded from the total since most of them seem to be included in the SFMP (DOE82a). The HLW has also been excluded. The total volume of wastes at the Hanford complex (including SFMP) is one to two orders of magnitude greater than the values listed.

Several of the activities listed in Table 3-27 are still in the construction phase. The Fuels & Materials Examination Facility is in a fairly advanced stage of construction in which prototype equipment is being designed (ANS82). The Fusion Materials Irradiation Testing Facility (DOE78c) has had funding difficulties, but as of March 1982 was proceeding. The High Performance Fuel Laboratory (ERDA77e) has evolved into the Secure Automated Fabrication Experiment (SAFE) for production of high performance fuels (FFTS and breeder reactors) and the Wet Scrap Recycle (WSR) facility for processing scrap from SAFE. The latter facilities are not projected to be on line until the late 1980s and are not listed in Table 3-27.

Los Alamos National Laboratory - The Los Alamos National Laboratory (LANL), formerly the Los Alamos Scientific Laboratory, was established in 1943 as a site of the U.S. Army's Manhattan Engineering District. The

TABLE 3-27

HANFORD RESERVATION SUMMARY

Facility or Activity	Primary Nuclides	D&D Wastes (m^3)	D&D Wastes (Ci)
100 Areas Production Reactors			
4 Defueled in SFMP (DOE82a) (2000 Mw/each)	AP		
4 Defueled, in reserve (2000 Mw/each)	AP	7,200	176,000[a]
N Production Reactor 2000 Mwt; power and Pu prod.)	AP	6,800[b]	44,000[a]
200 Area			
Purex Reprocessing Plant (inactive, but being brought back on line)	FP, TRU	12,000	10,000
B Plant; remove Sr and Cs from HLW	FP	8,500	10,000
Associated Cribs, seepage pits, etc (some on SFMP)	FP, TRU	10^6	Large
Storage of TRU waste five locations (NRC79, K179, et al)		80,000	100,000
400 Area			
Fast Flux Test Facility (400 Mw)[c]	FP, AP, TRU	10,000	820,000
Fuels and Materials Examination Facility (Construction Phase)	FP, AP, TRU	Unknown	
Fusion Materials Irradiation Testing Facility (Construction Phase)			
300 Area			
Reactor Fuel Fabrication Facilities[d]	U, Some FP	3,000	100 kg U
Appendix C Indicates 5 Accelerators			
Subtotal (Excludes TRU waste, cribs and seepage pits, and accelerators).		$4.8\text{x}10^4$	$1.1\text{x}10^6$

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[a] See reference production reactor, Appendix A. Excludes short half-life activation products (reactors shutdown for over 10 years). Only includes waste volume from reactor. Other wastes appear to be in SFMP program (DOE82a).

[b] Includes waste from reactor, but only one-half of other wastes.

[c] Based on reference test reactor, scaled up by factor of two, includes a large contribution from short half-life material, compared to the production reactor inventory.

[d] Equated to one half the wastes from a 1000 Mt/yr reference fuel fabrication plant.

laboratory, located on a mesa north of Albuquerque, New Mexico, has facilities covering about 0.41 km^2 on a 109 km^2 site. Its role was designing, constructing and testing World War II atomic weapons. In 1947 the site was renamed and its mission broadened. LANL is operated by the University of California. The present mission is the application of science and technology to solve national problems both in nuclear weapons development programs and in energy supply and conservation projects (DOE78b, DOE79c, NRC79). The major facilities are research reactors, R&D facilities including hot cells, a new plutonium facility, an 800 MeV linear proton accelerator, a Weapons Neutron Research facility for weapons effects simulation, and a stable isotopes production facility (DOE79c).

The site has used shallow land burial for the disposal of radioactive waste since mid-1946. A variety of special disposal operations have been performed at the site, ranging from the shaft burial of a few grams of tritium-contaminated solution to the demolition and burial of entire buildings. Pits, tanks, shafts, underground chambers and absorption beds have been used to dispose of both solid and liquid low-level wastes. The buried waste, originating from both defense and non-defense programs, has a total volume of $2.55x10^5$ m^3 and the activity is less than $4x10^5$ Ci. Only two locations, G and T, at LANL are presently being used for LLW disposal (DOE78, DOE78b, NRC79).

The Los Alamos National Laboratory includes a number of laboratories and development facilities involved with the development of plutonium technology in support of the nuclear weapons program. Transuranic waste from these facilities is stored at LANL. The volume of stored TRU waste is

1.95×10^3 m^3, and the activity is 10^5 Ci (NRC79).

A Waste Volume Reduction Facility is under consideration at LANL. Its operation is planned for the mid-1980s. The facility may include an incineration capability for burning TRU wastes (NRC79).

The active facilities and projected D&D wastes for LANL are listed in Table 3-28 (DOE78b, DOE79c). As at the other major laboratories, there are facilities listed in the table that are also in the SFMP (DOE82a).

The estimates in Table 3-28 indicate the TRU stored waste volume is only a fraction of the total D&D waste volume, but the curie content of the stored TRU is much larger than the wastes from projected D&D activity. It is speculated that there are significant volumes of contaminated soil and facility materials not included in this summary.

Lawrence Livermore National Laboratory - The Lawrence Livermore National Laboratory (LLL), formerly Lawrence Livermore Laboratory, is a mission oriented research and development laboratory established in 1952 in Livermore, California. Its current missions include nuclear weapons design, development of new technologies to expand the energy resource base, and providing biological and environmental data that help guide the recovery and use of energy in environmentally acceptable ways. Major facilities include Magnetic Fusion Energy facilities; laser fusion facilities; geothermal test facilities; Site 300, a 28 km^2 chemical explosives test site; the research computer center (one of the world's largest); research and testing facilities in rock mechanics, chemistry, chemical engineering, metallurgy, meteorology, etc; and engineering and machine shop facilities.

TABLE 3-28

LOS ALAMOS NATIONAL LABORATORY SUMMARY

Facility or Activity	D&D Wastes (m^3)	D&D Wastes (Ci)
Reactors		
Aqueous Homogenous	35	1,400
Clementine, Hg Cooled, Pu Fueled Fast	35	1,400
Omega West (8 Mw)	35	1,400
LA Power Reactor Exp. LAPRE I and A	SFMP	
HE Cooled Ultra High Temperature UHTREX	SFMP	
LA Molten Pu Reactor Exp. (LAMPRE; D&D Complete)	SFMP	
Clinton Anderson LA Meson Physics Facility (Includes 800 MeV Proton Accelerator)		
Other Accelerators		
8 MeV Van de Graaff		
15 MeV Tandem Van de Graaff (can be added to 8 MeV)		
Appendix C lists a total of 8 accelerators at LANL		
Pu Fabrication Facility (new facility completed 1979, 18,000 m^2 floor area)[a]	9,000	18,000
Weapons Neutron Research Facility (Sycllac)		
Eight Beam CO_2 Laser Facility		
Antares (under construction, laser fusion)		
Detonation Facility (3000 m^2 could be contaminated with depleted U)		
Target Fabrication for Fusion Experiments		
2 Waste Treatment Facilities		
Pu effluent (about 42 mCi as of 1972)		
Stored TRU Waste	2,000	10^5
Other Waste Disposal (trenches and cribs)		
Subtotal, excluding TRU and accelerators	9,100	22,000[a]
Total, excluding accelerators	11,000	10^5

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[a] See assumptions for Rocky Flats; 0.5 m^3 waste per m^2; and 2 Ci Pu per m^3 waste. Pu estimate may be conservative, since it is equivalent to about 300 kg of Pu and the plant inventory may be only 100 kg (DOE78b).

The laboratory site has an area of 2.6 km^2 and 0.29 km^2 of facilities. Sandia National Laboratory also has facilities at LLNL (DOE79c).

Radioactive wastes originate in less than 10 percent of the buildings (e.g., 20) at LLNL. These wastes consist primarily of laboratory refuse and radioactive liquids. The majority of LLNL originated wastes are produced in five facilities: Building 281--Pool Type Reactor, Building 194--100 MeV Linear Accelerator, Building 251--Heavy Element Chemistry, Building 332--Metallurgy Chemistry, and Building 331--Light Istope Chemistry. There are no active permanent waste storage or disposal areas at these buildings (NRC79).

Site 300 of the LLNL complex has been used for the disposal of low-level waste. Two disposal pits are identified at this site. Some unmarked burial locations from early burial activity are also at the site. The volume of waste in the two pits is 1.4×10^4 m^3, and the activity is 3.5 Ci. Both disposal pits are in use. Some solid waste has been generated in the explosive test area from the testing of devices. The radioactive residue in this waste material is primarily depleted uranium, although some enriched uranium and natural thorium are also present (NRC79).

Low-level plutonium contamination is also present in soil from solar evaporation of liquid wastes. The soil concentrations are less than 1 pCi/g (ERDA77g).

The activities at the LLNL are summarized in Table 3-29. Information was not available on building sizes or existing building contamination or projected D&D wastes. A rough estimate of D&D waste can be made from the information that waste originates from 20 of the 244 buildings and that the

TABLE 3-29

LAWRENCE LIVERMORE NATIONAL LABORATORY SUMMARY

Facility or Activity	Nuclides	D&D Waste (m^3)	D&D Waste (Ci)
Pool Type Reactor [a]		35	1,400
100 MeV Accelerator			
14 MeV Rotating Target Neutron Source (Appendix C lists 6 additional accelerators)			
Gaseous and Metallurgical Facility			
High Explosive Processing and Test Facility			
High Explosive Flash Radiography Facility			
Magnetic Fusion Energy Facility			
Mirror Fusion Test Facility			
Tandem Mirror Experiment (under construction)			
LL Buried Waste (1.4×10^4 m^3, 3.5 Ci buried)			

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[a] Based on reference research reactor.

total floor space of all buildings is 0.29 km^2 (DOE79c). Assuming that the amount of contamination is relatively less than the reference fuel fabrication and conversion plants a D&D waste factor of 1 m^3 per 10 m^2 of floor space is used (compared to 1:6 for E180, E181a). Based on this information a D&D waste volume of about 2000 m^3 is estimated. This waste would contain plutonium, uranium and tritium, and possibly other radionuclides. An estimate of 1 Ci/m^3 is used to obtain an estimate of the inventory.

Oak Ridge Facilities - There are three DOE sites in the Oak Ridge, Tennessee area: Oak Ridge National Laboraotry, 2.6 km^2 (ORNL), Oak Ridge Gaseous Diffusion Plant, 4 km^2 (ORGDP), and Oak Ridge Y-12 Plant, 2.6 km^2 (Y-12). Because of their close proximity they have been treated as a single facility. Two smaller DOE facilities, the Comparative Animal Investigation Laboratory and Oak Ridge Associated University Labs are also located in this area (DOE79c, NRC79).

The missions of the three major sites are different. However, they are all under the direction of the DOE Oak Ridge Operations Office and all are operated by the Nuclear Division of Union Carbide Corporation. The Oak Ridge National Laboratory is a multiprogram institution whose principal goal is developing safe, economic, and environmentally acceptable technologies for efficient production and use of energy. Laboratory activities cover a broad range of interrelated functions: basic research, pilot plant operations, and large scale high technology development. The program is conducted in four general areas that are roughly equal in size: fission energy development, biomedical and environmental research, basic energy science, and magnetic fusion. In addition, there are programs in fossil energy and conservation (DOE79c).

The Oak Ridge Gaseous Diffusion Plant (ORGDP) was developed to produce enriched uranium for defense purposes. Over the intervening years, emphasis has changed to the production of slightly enriched uranium for commercial power reactors. The plant also conducts research on gaseous and centrifugal enrichment and produces the barrier material for all of the enrichment plants (DOE79c). The plant buildings cover an area of about 0.42 km^2. Prior to the recent upgrading, the facility contained over 4000 separation stages (AEC68).

The Oak Ridge Y-12 Plant's primary emphasis is support of the nuclear weapons program, although the plant does provide support to other Union Carbide Corporation Nuclear Division facilities in Oak Ridge and other government agencies. The plant has facilities for recovery of enriched uranium from scrap, fabricating uranium and other metal components, and producing lithium compounds (DOE79c).

Since the missions of these sites are different, their major facilities are likewise different. The ORNL major facilities (0.24 km^2 building area) consist of nuclear reactors, particle accelerators, chemical processing development facilities, fusion devices, an extensive and varied biological laboratory complex, an environmental sciences laboratory, and the nearly completed Holifield Heavy Ion Research Facility. The ORGDP major facilities consist of five gaseous diffusion cascade facilities supplemented by some 70 support facilities which have a combined area of 0.3 km^2 (ERDA75b, ERDA76). The Oak Ridge Y-12 Plant's major facilities consist of weapons related production areas, storage areas, R&D areas, and support facilities (ERDA77g).

All three sites generate low-level waste and, in addition, ORNL also generates intermediate-level waste (ILW)* and TRU waste. Low-level waste has been disposed of at ORGDP in three burial grounds: two old classified waste burial grounds and a new classified waste burial ground. The old sites are inactive. The reported total volume of burial excluding the old classified areas is 1.4×10^5 m^3, and the activity is 14 Ci (NRC79, To79).

The Y-12 plant has four burial grounds: 1-A, 2-B, 3-C and a classified area. The burial grounds contain about 9×10^4 m^3 of LLW with an activity of about 6.8×10^3 Ci. All these burial grounds are active (NRC79).

Low-level waste has been disposed of at the Oak Ridge National Laboratory in the solid waste storage areas and Burial Grounds 1 through 6, in trenches and auger holes. Wastes have originated from ORNL activities, commercial operations, and other Federal activities. The volume of low-level waste in these burial grounds is 1.8×10^5 m^3. The true curie content is unknown because of lack of reliable data covering years prior to 1977 but is estimated to be 10^5 Ci. Only Burial Ground 6 is active (NRC79).

In addition to solid LLW, other low-level waste has been disposed of in ponds and basins throughout the site. These ponds and basins are associated with reactors, process facilities and waste management operations. One of the ponds is located in Burial Ground 5. It contains 61 m^3 of low-level liquid waste from the low-level waste treatment plant, and contains less than 15 curies (principaly Sr-90). The pond is currently receiving radioctive waste. There are two ponds or basins (Homogeneous Reactor Test (HRT) basin and basin #3513) associated with discontinued operations that are part of SFMP, but they are not located in the burial grounds. The HRT basin was used for low-level waste disposal, and has been filled and paved over. The volume and curies of LLW located there are unknown (NRC79).

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* This is a unique waste classification used for the product of a special waste treatment process used at ONRL: Certain wastes are gathered. A sludge containing most of the uranium and transuranics settles out. The liquid is concentrated by evaporation.

Basin No. 3513 has 3.40×10^3 m^3 of LLW containing 238 curies. The basin is retired, but is being used for ecological studies (NRC79, To79).

Oak Ridge National Laboratory contains a variety of chemical processing development facilities supporting the laboratory's fission energy development mission. The transuranic waste from these operations has been stored in 21 trenches and three buildings located in Burial Ground 5. The volume of stored TRU waste is 1.1×10^3 m^3, and the activity is 8.1×10^4 curies. The trenches in Burial Ground 5 are in active use as are Buildings 7826 and 7827. Building 7829 contains representative pieces of irradiated reactor fuel and control rods from the Peach Bottom I reactor (NRC79, To79).

Several storage and disposal options have been used for ORNL intermediate level waste from the fission energy programs. Some of the waste had been disposed of in four pits (numbered 1 to 4) and four trenches (numbered 5, 6, 7A, and 7B). These pits and trenches, which contain 2×10^5 m^3 of waste with an activity of 10^6 Ci, were retired in 1979 (NRC79).

Other waste was stored in six gunite tanks. The supernate from the tanks, after sludge settled out, was removed and mixed with concrete and injected into shale beds 800 to 900 feet below the surface with a hydrofracture facility. A new tank farm and injection facility became operational in the years 1979 to 1981. The old facilities were to be deactivated in 1979 and are in the SFMP list (NRC79, To79, DOE82a). The settled sludge, accumulated in the bottom of the tanks, is scheduled for removal in 1983 (NRC79). The volume of the sludge is estimated to be 1.5×10^3 m^3, with an activity of about 10^6 Ci (mostly Sr-90) (NRC79, To79).

The new tank farm has two collection tanks and eight storage tanks. A new evaporator, plus the old existing evaporator, are used to concentrate the waste. The new hydrofracture unit combines both the supernate and sludge with cement and injects the mixture into the subsurface shale beds.

The facilities at the Oak Ridge sites are summarized in Table 3-30 (DOE79c, NRC79, DOE82a). The waste estimates in the table are very incomplete, because of the lack of information. However, it is evident that there are large quantities of TRU and other wastes in trenches and pits. The ILW pits and trenches do not appear to be in the SFMP (DOE81c, DOE82a). Order of magnitude estimates for ORNL and Y-12 (Gaseous Diffusion Plant Covered by Be82a) are about 10^6 m^3 of D&D wastes. The activity for ORNL is largely fission products, with some activation products and TRU. A general estimate of activity is 10^6 Ci.

Savannah River facilities - Three different laboratories are located on the Savannah River site, which covers an area of 1000 km^2. The Savannah River Plant (SRP), near Aiken, South Carolina, was built in the early 1950s for producing and reprocessing plutonium for nuclear weapons. This is the

TABLE 3-30

OAK RIDGE FACILITIES SUMMARY

Facility or Activity	D&D Waste (m^3)	 (Ci)
Heavy Ion Research Facility		
Isotopes Separation Facility		
Transuranic Processing Plant		
High Flux Isotope Reactor		
Oak Ridge Research Reactor	1,100	41,000
High-Level Radiochemical Lab	1,100	41,000
Materials Processing Lab		
Thorium Uranium Fuel Recycle Facility		
High Radiation Level Examination Lab		
Environmental Sciences Laboratory		
Electron Linear Accelerator		
Oak Ridge Isochronous Cyclotron (Appendix C lists a total of 12 accelerators)		
Fission Products Dev. Lab (SFMP)		
Gunite ILW (6) Storage Tanks (SFMP)		
Old Hydrofracture Facility (SFMP)		
Curium Facility (SFMP)		
Molten Salt Reactor (SFMP)		
Metal Recovery Facility (SFMP)		
Homogeneous Reactor Exp. (SFMP)		
Fission Product Pilot Plant (SFMP)		
Low Intensity Test Reactor (SFMP)		
ORNL Graphite Reactor (SFMP)		
ILW in Pits and Treches	$2x10^5$	10^6
TRU "Stored" Wastes (Trenches in Burial Grounds)	1,000	80,000
Area 5 Pond	1,100	10^6
Gaseous Diffusion Plant		
Produce membranes for all gaseous diffusion plants		
About 1000 or more diffusion cascades		
Waste facilities		
Y-12 Plant		
Fabrication of Uranium		
Recovery of U from scrap		
Produce lithium compounds		
Total	$2.0x10^5$	$2.2x10^6$

major activity at the site. The Savannah River Laboratory (SRL) provides support to the plant and also has separate program areas which include special materials and waste management, research and development on the fuel cycle, and environmental research. The Savannah River Weapons Facility's (SRWF) programs deal with nuclear weapons production. All three laboratories are included in this section. Savannah River's primary mission is to produce nuclear materials--primarily plutonium, heavy water and tritium--to meet requirements of the Department of Defense for nuclear weapons. Major plant facilities were built during 1950 to 1955, and many are presently in operation. The plant is operated by E.I. du Pont de Nemours under the Department of Energy's Savannah River Operations Office (DOE79c).

The activities of the laboratories are listed in Table 3-31. Limited information is also given on present waste volumes and projected D&D wastes (ERDA77g, DOE79c). The DOE SFMP list (DOE82a) lists the Heavy Water Comp. (asumed to be components) Test Reactor as surplus. It is assumed this is one of the small test reactors; however, it could be the one assumed to be equal to a full test reactor.

Low-level waste has been disposed of at the Savannah River Plant by burial in the 200 area. Solid wastes have been disposed of in pits and trenches. The volume of low-level waste located in the 200 area is $2.53\text{x}10^5$ m^3, and the activity is $3.88\text{x}10^6$ Ci. The burial area is active.

In addition, liquid low-level waste has been disposed of in seepage and retention basins throughout the site. These basins are associated with reactors, process facilities, and waste management operations. The twelve basins in the 200 area handle low-level waste from both the separation

TABLE 3-31

SAVANNAH RIVER FACILITIES SUMMARY

Facility or Activity	D&D Waste	
	(m^3)	(Ci)
Reactors		
2 Low Power Test Reactors (assume equivalent to research reactors)	70	2,800[b]
Critical Assembly	10	1[c]
Heat Transfer Laboratory		
Reactor Hydraulics Test Facility		
Isotopes Process Development Lab		
Carbon Test Facilities		
Analytical Chemistry Lab		
Production Reactors (Heavy water, concrete shielding)		
3 Active (Reactors P, K and C in Area 100)	20,400	134,000[d]
2 Standby (Reactors R&L Area 100)	13,600	88,000[d]
Test Reactor (Standby) 305m	1,100	410,000[a]
Fuel Reprocessing (Area 200)		
Plant F[e]	11,000	10^4
Plant H[e]	11,000	2×10^4
Assoc. Seepage Basins and Tank Farms (51 tanks), etc[e]	236,000	10^5
Heavy Water Extraction and Recov. Plant (Area 400)		
Target and Fuel Fabrication (Area 300, M)		
LLW Seepage and Retention Basins (12)		
LLW Burial Area (0.8 km^2)		
3 Accidental HLW Releases in Area 200 (Overflow of Tanks 16 and 8, and leak)	Unknown	4,000
TRU Waste Storage Area		
Spent Fuel Basin (Probably includes N.S. Savannah Fuel)	3×10^4	3×10^5
HLW Processing (Concentrate by Evaporator)	500	Small
Transuranic Waste Treatment Facility (Scheduled for 1989)		
No Accelerator reported at the facility		
Total (Excluding TRU)	3×10^5	7.7×10^5

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[a] Used reference test reactor.

[b] Used reference research reactor.

[c] Used reference mockup reactor/critical facility.

[d] Based on reference production reactor. Assumes shut down for several years and defueled. Waste volume is for reactor plus 30% of soil related material (i.e., reactors are closed loop coolant).

[e] Estimates are taken from Appendix B.

(reprocessing) facilities and the tank farms. Classified LLW is also stored in two vaults. Finally, LLW exists as contaminated soils at various other locations on the site. The waste has been caused by spills, equipment failure, and the like (NRC79).

Nuclear production reactors and chemical separations plants are the primary sources of transuranic waste. TRU waste is stored at SRP in area 200. The solid wastes have been stored in drums and concrete cylinders placed on storage pads and in trenches. The volume of transuranic waste located in the burial and storage ground is about $2.7\text{x}10^4$ m^3 with an activity of $3\text{x}10^5$ Ci. The 200 storage area ground is active (NRC79).

A transuranic waste treatment facility is planned for operation in 1989. This facility will process presently stored TRU waste which has an activity greater than ten nanocuries of transuranic material per gram of the mixture. Furthermore, if an off-site repository is not available, SRP plans to have an engineered storage facility for TRU in operation by 1989 (NRC79).

The production of nuclear materials at the Savannah River Plant has resulted in the production of high-level wastes which have been stored in the 51 tanks in the 200 area (F and H tank farms).

Liquid wastes (supernatant and sludge) and solid waste (salt cake) are in the tanks. Most of these stored wastes originated from the defense program. The volume of high-level waste located in the tank farms is $8.33\text{x}10^4$ m^3, and the activity is $7.75\text{x}10^8$ curies. There has been no intentional release of high-level waste to soils; however, there has been at least one tank leak and two tanks which overflowed.

The information in Table 3-30 is incomplete, but helps characterize the Savannah River facilities. There may be a fairly large volume of contaminated soil and rubble not accounted for in the table.

In addition to the large laboratories with diverse programs there are other laboratories which have broad programs. These laboratories are:

Ames Laboratory
Lawrence Berkeley Laboratory
Mound Facility
Sandia Laboratory
Bettis Atomic Power Laboratory
Knolls Atomic Power Laboratory

Ames Laboratory - The Ames Laboratory is a university owned laboratory supported by the DOE. DOE79c and ERDA77g describe it as a DOE laboratory.

The facility has a laboratory (0.03 km^2 area) on the university campus and a facility about 2 km northwest of the campus (0.16 km^2 area) (DOE79c, ERDA77g). A 5 Mw research reactor which was located at the off-campus site, has been shut down and dismantled. The laboratory no longer has any significant radiation facilities.*

DOE79a reports that there is about 2 m^3 of uranium and thorium waste material on the site. Apparently there are about 100 g of uranium and 20 g of thorium in the material. It is possible this material may have been removed.

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* Personal Communication, R.S. Hansen, Ames Laboratory, April 4, 1982.

Lawrence Berkeley Laboratory (LBL) - LBL in Berkeley, California is operated by the University of California and is located on university property. The principal programs are energy technology, energy research, environmental and health, and energy conservation. The floor space of the laboratory is 0.10 km^2.

The pertinent facilities related to radioactive wastes from D&D are the following (DOE79a, DOE79c).

- Alloy preparation and characterization facilities (not necessarily radioactive material)
- Animal colony and tissue culture facilities
- Bevalac
- 88 inch cyclotron
- Sealed sources; 15,500 Ci of Cs-137 and Co-60

The only activities expected to give any significant D&D wastes are the Bevalac and the cyclotron--these are discussed in Chapter 10.

DOE79a reports that there are 2200 Ci of activity associated with the facilities. About 2100 Ci of this is associated with Building 75, the Radioisotope Service Lab. Much of this activity may be tritium.

It appears that any D&D wastes from LBL (excluding the accelerators) will be small compared to the total for DOE facilities.

Mound Facility - The Mound Facility was established in 1948 to support the nuclear weapons program. The facility, owned by DOE, is operated by

Monsanto Research Corporation on a 0.72 km^2 site in Miamisburg, Ohio. The buildings cover an area of about 0.1 km^2 (ERDA77g, DOE79e).

The initial program was to determine the chemical and metallurgical properties of polonium. More recently the primary function has been manufacturing chemical explosives used in weapons. The mission of the lab has been further expanded to include recovering and purifying tritium from wastes received from other plants, developing and fabricating radioisotope heat sources, and isotope enrichment. Polonium operations were terminated in 1972 (DOE79c, DOE79e).

Radioactive waste has not been specifically disposed of on site (DOE79e). Also, the site is not listed in NRC79. However, areas of the site are contaminated with plutonium (primarily Pu-238), Ra-226, Ac-227, Th-232, Co-60, Th-228 and probably tritium (DOE79e).

Laboratory facilities and areas of contamination are given in Table 3-32 (DOE79e). The SM Building and Sanitary Disposal Plant are listed in SFMP (DOE82a).

There is sufficient information to obtain a rough estimate of the volume of existing contamination, but it is very difficult to even make approximate activity estimates (see Table 3-32).

Sandia National Laboratories - The Sandia National Laboratories founded in 1945, are located on a 1.15 km^2 site within the confines of Kirkland Air Force Base, in Albuquerque, New Mexico. Buildings cover 0.27 m^2 of the site. A testing range is maintained by Sandia at Tonopah, Nevada. Although little information is available on it, it is included in

TABLE 3-32

MOUND FACILITY SUMMARY

Facility or Activity	Nuclides	Existing Contam.	D&D Waste[f] (m^3)
T Recovery and Purification (by cryogenic adsorption)	Tritium		
Development and Fabrication of Radioisotope Heat Sources	Pu-238 as PuO_2		1,000[a]
Isotope Enrichment Pu-231, Th-229, and 230, U-234 and recover Pa-231 and Th-230 from pitchblend in gram quantities	Subject isotopes		
Contaminated Areas (DOE79e)			
Waste Tank Overflowed in 1965	Po-21 (decayed), Co-60		
Sewage Disposal Sludge Drying Pits	Trace levels of Pu-238		
Rad. Waste Line Break, 1969	Po-210 (decayed), Co-60	630	190[b]
Buried Empty Thorium Drums, 1954-65	Ra-222, Th-228, and 232, Ac-227	2000m^2	2000[c]
Buried Contaminated Dirt (Th-232)	Th-232	2300m^2	2300[c]
Contaminated by Processing Operations (before 1965)	Pu-238	240m^2	72[b]
Buried Contaminated Dirt (1965)	Th-232 and progeny	1800m^2	1800[c]
Pu Underground Waste Line Break (27 m^3 shipped off site)	Pu-238		
Buried Steel Crane, Tracks, Shielding Panels (1958-1960)	Th-228, Ra-226 Ac-227	93m^2	190[d]
Sanitary-Sewage Septic Tank and Leach Basin (1960-65)	Pu-238	1400m^2	420[b]
Area Under and Around Process Building (1960-70)	Pu-238	3700m^2	1100[b]
Silt and Dredgings from Onsite Drainage Ditch, Used on Landfill (1971-74)		5600m^3	3400[e]
Subtotal From Facilities	Pu-238, Th, U Decay Chain		1100
Subtotal Contaminated Soil			11,000
Total			12,000

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[a] Assuming 10% of buildings are used for T recovery, heat source fabricator, or isotope enrichment and the D&D waste to floor space ratio is $1m^3$ to $10m^2$ ($0.1x10^6$ m^2 x 10% x1 $m^3/10m^2$ = 1000 m^3).

[b] Assume 30 cm depth.

[c] Assume 1m depth.

[d] Assume 2m depth.

[e] Assume 60 cm depth.

[f] No estimates of waste activity are available.

the Nevada Test Site description. Sandia also has a facility adjacent to the Lawrence Livermore National Laboratory (LLNL), which is included in the LLNL section. Western Electric Company operates the laboratory for DOE (DOE79c).

The Sandia Laboratories were started as part of the Manhattan Project. While considerably enlarged since then, Sandia's responsibilities have remained fundamentally the same: to conduct engineering research leading to new weapons concepts, design and develop nuclear ordnance, verify readiness of the nations stockpile and modify weapons to meet new requirements.

The facilities, which include pulsed reactors and accelerators are designed for weapons effects studies, surface physics, research and microelectronics development, and non-destructive testing and quality assurance evaluations (DOE79c).

Low-level waste has been disposed of in several areas. Small quantities of suspected alpha contaminated waste were buried in the old site in Tech. Area II prior to 1960. The total TRU content is estimated to be less than 1 g of Pu-239. There is no TRU waste in the new site in Area III. Sandia started generating TRU waste in 1979. This waste is shipped to LANL for storage (NRC79). The present LLW site is segregated into an area for LLW and an area for classified waste.

Table 3-33 lists some of the facilities at Sandia. Given the limited information available on the facilities, the only projections of D&D wastes are for the pulsed reactors and the accelerators (given in Chapter 10). The estimates are too incomplete to attempt totaling values. As an order of magnitude estimate, based on the type of activities, it is assumed that

TABLE 3-33

SANDIA NATIONAL LABORATORIES SUMMARY

	D&D Waste	
Facility or Activity	(m^3)	(Ci)
Research Reactors (Pulsed) In Area V		
SPP (Enriched U), built 1961	35	1400[a]
ACPR, Pulsed Triga, built 1967	35	1400[a]
Electron Beam Accelerators		
Van de Graaff		
Cockroft-Walton		
(See Chapter 10, Appendix C lists 3 accelerators)		
Explosion Testing Area		
Combustion Laboratory		
Waste Disposal Sites 1.4x10^3 m^3; 6x10^3 Ci		
Old Inactive Site in Area II (Closed in 1960)		
Active Site (pits and trenches), Area III		
Classified Nuclear Weapons Components		
Unclassified LLW		
Future Expansion		

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[a] May be an overestimate, depending on duty cycle of reactors.
[b] Contaminated with tritium and depleted uranium.

10 percent of the buildings (0.07 km^2x0.1) will require D&D and that the average waste to building area factor for fuel fabrication and conversion plants is applicable (i.e., 1 m^3 per 6 m^2) (E180, E181a). Including material from the reactors, this gives a D&D volume of about 500 m^3. The total curie content is projected to be similar to that from the reactors.

Bettis Atomic Power Plant - The Bettis facility includes two sites which are operated by the Westinghouse Electric Corporation for DOE. The principal site, known as the Bettis Site, is about 16 km (10 miles) from Pittsburg. The site covers about 1 km. The second site, the Naval Reactors Facility (NRF) is at Idaho National Engineering Laboratory, in Idaho. NRF is included in the description of INEL (DOE79c).

The primary objective of the Bettis Site is research and development for naval nuclear propulsion plants and the Shippingport Reactor (Shippingport is on the SFMP list, DOE82a, and is listed under other facilities).

The Bettis facilities include three prototype Naval reactors (at INEL), a hot laboratory for evaluating materials after they are irradiated, nuclear core process development laboratories, several critical facilities, and thermal hydraulic test facilities, and the expended core facility where materials from spent cores are dismantled and examined. There is some uncertainty as to which facilities are at the Bettis site. However, it is assumed the Bettis site includes the critical facilities and a hot laboratory and the core development laboratory. There is minimal information on the facility, but based on the above facilities and the information in

Appendix A on test reactor and critical facilities the D&D wastes are projected to amount to hundreds of cubic meters of waste and roughly 100 Ci of fission products (based on several hot labs, machine shops, and the critical facility). These estimates assume scrap and unused materials and excess equipment have been cleaned up prior to the D&D process. The NRC (NRC79) reported that there are no known low-level or high-level waste burial grounds at Bettis. Appendix C lists three accelerators as being located at Bettis. The waste from these is considered in Chapter 10.

Knolls Atomic Power Laboratory (KAPL) - KAPL includes three sites which are operated by General Electric Company for DOE. The principal site is the Knolls site (0.7 km^2) in Nishayuna, New York. The other sites are Kesselring, in West Milton (16 km^2) New York and at Windsor, Connecticut (0.04 km^2). The primary mission of KAPL is similar to that of Bettis--development of improved naval nuclear propulsion plants and reactor cores (DOE79c, ERDA77g) and training for Navy personnel (DOE81c).

A specific assignment was the development of the reactor (S8G) for the Trident ballistic missile submarines. This included construction of a full-scale propulsion plant prototype at the Kesselring Site (DOE79c, AEC72a). The Trident is the replacement for the aging Polaris submarines (AEC72a).

Three additional naval nuclear powerplant prototypes are at the Kesselring site. A prototype reactor is also located at the Windsor site. These prototypes are probably for the Nimitz-class aircraft carriers and the Los Angeles-class nuclear-powered cruisers (DOE79c, ERDA77g).

The main features of the Knolls site appears to be chemical, physical and metallurgical facilities. There are also waste treatment facilities at this site. The Separations Process Research Unit (SPRU), which is also located at the KNolls site (DOE81c) is on the surplus (SFMP) list (DOE82a). All the facilities of the SPRU, a pilot fuel reprocessing facility are listed as surplus. There are no recorded low-level or high-level waste burial grounds on the Knolls sites. However, ERDA77g does refer to a retention basin at the Windsor site.

The limited available information does not allow an accurate assessment of D&D wastes for the Knolls sites. A general estimate is obtained by relating the prototype reactors to the reference test reactor facility (Appendix A). The D&D wastes from each prototype are assumed to be equal to the waste from the test reactor and one half the wastes related to concrete and auxillary facilities (i.e., assume less support facilities are needed). The equivalent of the concrete and pipe wastes from a single reactor are assumed to be present on both the Kesselring and Windsor sites. Based on these assumptions the following waste projections are made:

	Volume (m^3)	Activity (Ci)
Reactor:		
7.5 m^3 x 4 reactors	30	
410,000 Ci x 4 reactors		1,640,000
Concrete and Auxillary Facilities:		
1060 m^3 x ½ x 4 reactors	2,120	
16 Ci x ½ x 4 reactors		32
Soil and Concrete Pipe, etc.		
3630 m^3 x 2 sites	7,260	
1 Ci x 2 sites		2
Total (rounded off)	9,000	1.6×10^6

Nuclear Materials Production Facilities

The nuclear materials production facilities cover diverse operations varying from research on exotic elements to the production of nuclear materials for weapons components, commercial power generation, and medical/industrial uses. The primary operations are:

- Feed materials plants (Fernald and Ashtabula).
- Uranium enrichment or gaseous diffusion plants (Oak Ridge, already discussed with Oak Ridge Facilities, and Portsmouth and Paducah).
- Plutonium and tritium production (already covered under Hanford and Savannah River).
- Fuel reprocessing (already covered under INEL, Hanford, and Savannah River).

The enrichment and feed material facilities are mentioned because they are DOE/government facilities, but they will also be treated in a separate report covering nuclear fuel cycle facilities (Be82a).

Paducah and Portsmouth Gaseous Diffusion - Paducah and Portsmouth plants enrich uranium by gaseous diffusion. They are discussed together because they are similar. The Oak Ridge Gaseous Diffusion Plant was mentioned in conjunction with the Oak Ridge site. Construction of a new facility, a centrifugal enrichment plant, was started next to the Portsmouth site in 1979 (DOE80g).

In addition to gaseous diffusion work, both plants have facilities for recovering HF from UF6 composed of depleted uranium (i.e., most of the U-235 and U-234 has been removed), for converting UF_6 to UF_4 (more stable for storage), and for other uranium conversion and recovery processes.

The Portsmouth site, owned by DOE and operated by Goodyear Atomic Corp., is near Piketon, Ohio, north of Portsmouth. The site covers an area of about 16 km^2. The buildings on site cover 0.4 km^2 area. The only radioactive waste generating process at the plant is the decontamination and recovery facility. The low-level waste facilities include two burial grounds (X-749-A and an unnamed classified burial ground). The volume of waste in the burial ground is about 10^3 m^3 and the activity about 6 Ci (NRC79). The activity is primarily uranium, but Tc-99 and trace amounts of TRU are present (ERDA76). The Tc-99 and TRU originate from processing uranium that has previously been irridiated. Tc-99 has a long half-life (2.12×10^5 years) and a lower removal during the purification process than most other fission products (ERDA76).

A sludge lagoon at the Portsmouth facility covers about a 0.18 km^2 area (scaled from a figure in ERDA77g).

The Paducah facility, owned by DOE and operated by Union Carbide is in McCracken County, Kentucky, about 20 miles east of the confluence of the Ohio and Mississippi Rivers. The site covers about 5 km^2, of which 3 km^2 are within a fenced in area (ERDA77g). Buildings cover an area of about 0.3 km^2 (NRC79, ERDA76).

Two of the primary references disagree slightly in describing the waste disposal facilities at Paducah. The summary in NRC79 reports on 13 areas while DOE79a reports there are 14 areas, including a sludge lagoon. Since the waste inventory of DOE79a is larger than that in NRC79, it appears that including the sludge lagoon and its waste accounts for the difference. The description of NRC79 is used for the 13 burial areas. The difference between the inventory of the two references is alloted to the sludge lagoon.

The primary method of waste disposal is burial. Of 13 low-level burial areas, three are currently active (not specifically identified). Wastes have been segregated by type: one solid waste pit, one uranium waste burial ground, one classified scrap burial yard, four other scrap burial areas, one trash burial area, two concrete burial areas, one contaminated uranium burial area, one UF_6 condenser, one grave, and one contaminated salvage burial area. The primary contaminant is depleted uranium with some Tc-99 and traces of TRU wastes from previously irradiated fuel (ERDA76). The inventory for the 13 areas is about $7x10^3$ m^3 with an activity of about 10^3 curies (NRC79). The postulated sludge pond is assumed to contain about $3.6x10^3$ m^3 of waste with an activity of about 250 Ci (i.e., the difference between inventories of DOE79 and NRC79).

A large amount of metallic materials are used in the diffusion cascades--the main process equipment. The primary contaminants will be uranium and Tc-99. Apparently a large amount of nickel is used in the equipment. The potential for recycle of equipment is limited because of contamination, the corrosive nature of UF_6, and national security requirements. These facilities will be assessed in Be82a.

Fernald Feed Materials Production Center - The Fernald plant, near Fernald, Ohio, is an industrial facility owned by the DOE and operated by

National Lead of Ohio. It is located on a 4.2 km^2 site and contains technical buildings with about 5,600 m^2 of floor space (DOE79c). The primary work at Fernald is the production of purified uranium metal compounds for use at other DOE sites. The product varies from depleted to slightly enriched uranium. Through 1976, the plants major feed material was semi-pure uranium concentrate which was converted to pure UO_3 or reactor-grade uranium metal.

The primary contaminant in wastes is uranium; however, some thorium work has been done and the processing of recycled uranium and thorium has introduced minimal amounts of TRU and mixed fission products (e.g., Tc-99) into the waste.

The plant is a large scale fully integrated facility capable of converting feed into finished metal target and fuel elements, converting concentrate and recycled material to refined uranium trioxide for use in the gaseous diffusion plants, solvent extraction refining of uranium nitrate solutions, and conversion of uranium trioxide to uranium dioxide or green salt (UF_4). The plant also has casting, rolling, and machinery facilities (DOE79c).

Most of the waste at Fernald has resulted from the conversion of uranium concentrates to pure uranium trioxide (UO_3) or reactor-grade metal. Five pits, numbered 1 through 5, have been used to dispose of low-level waste. The five pits contain about 3.3×10^2 m^3 of waste. Pits 1 through 5 have an activity of about 10^3 Ci. Pits 1 and 2 are no longer in active use. Pits 3, 4 and 5 are still in use. Although Pit 3 no longer has sufficient capacity to function as a settling basin, it is still being used for disposal of various solids and sludges (NRC79, NL77, NL73, To79). A new pit was placed in service in 1979. A figure in ERDA77g indicates the area of all the pits to be about 0.4 km^2.

Fernald is storing low-level waste in three tanks: the metal oxide tank and two K-65 tanks. This waste originated in both defense and non-defense programs. The material in the metal oxide tank is U.S.-owned. It has a volume of 3.5×10^3 m^3 with a radioactive content of about 6 curies (U). The material in the K-65 tanks is owned by other countries. The volume of this material is 5.5×10^3 m^3 and the activity is about 1,650 curies (U, Th, Ra). None of the tanks, which are all owned by DOE, are currently receiving low-level waste (DOE79a, NRC79).

Uranium conversion and fabrication are treated in more detail in the fuel cycle report (Be82a). Rough estimates of the D&D wastes from this plant can be obtained by relating it to the reference uranium conversion facility (E181a). The estimate D&D wastes from the facilities is about 900 m^3, which is considerable less than the waste volumes from cleanup of the site (this assumes a D&D waste volume to building area factor of 1 m^3: 6 m^2). The total D&D volume is about 10^4 m^3.

Ashtabula Extrusion Plant - Ashtabula is a privately-owned facility which houses two DOE-owned extrusion presses (two buildings totaling 3000 m^2). The facility is not mentioned in the facility lists of NRC79 or ERDA77g, but is listed as a DOE facility in DOE79c.

The primary function of the facility is to extrude ingots of depleted uranium into tubes and fabricate ingots of slightly enriched uranium into billets. The tubes of depleted uranium are returned to Fernald for finishing after which they are shipped to Savannah River for use in the production reactor. The billets are shipped to Hanford where they are formed into fuel elements for the N-reactor.

The contract for the facility dates back to 1952. Since then the facility has performed a wide range of uranium forming processes.

The pertinent government facilities are a pyrophoric materials incineration facility (190m^2), a metallurgical laboratory and processing area (1200 m^2), a maintenance machine shop (190 m^2) and a materials storage and supply area (120 m^2).

The facility is about one-sixth the size of the reference fuel fabrication facility (E180), but probably would produce less than one-sixth of the 3000 m^3 D&D waste estimated for the fuel fabrication facility because of the more limited activities. No information was found on site contamination related to the DOE activities. The D&D waste volume is estimated to be 300 m^3 containing 10 kg of uranium, or less than 1 Ci of U-238.

Weapons Production and Test Laboratories - LANL, LLNL, and Sandia design weapons which are then tested at the Nevada Test Site. Following the successful completion and certification of a new weapons system, the production phase is begun at the production laboratories. Interwoven in the development, testing, production and stockpiling of weapons is the continued testing of devices to insure safety and operational capabilities. Eight complexes are included in this category. Bendix in Kansas City; Nevada Test Site; Rocky Flats; Mason and Hangar in Pantex, Texas; and General Electric in Pinellas, Florida, are covered in this section

(DOE79c). Monsanto, at Mound, Union Carbide Y-12 at Oak Ridge, and duPont at Savannah River were discussed with the respective facility complexes.

The Bendix, Kansas City, Missouri, plant, which was established in 1949, appears to be limited to non-nuclear weapon components. The Bendix activities are oriented to electrical and electric work, mechanical components, and plastics. The plant is listed as a DOE facility (DOE79c), but is not listed with facilities having environmental reports (ERDA77g) or Federal facilities with radioactive waste activities (NRC79). Therefore, a specific section is not written for it.

The Nevada Test Site (NTS), established in 1950, is part of and is surrounded by the Nellis Air Force Range. The 3,500 km^2 site is in southern Nevada, about 105 km north of Las Vegas, Nevada. Reynold's Electric Co. is the prime support contractor. The primary mission of NTS is to provide a remote secure facility for safely conducting nuclear tests in support of national defense programs.

The NTS has been used for conducting surface, cratering, and underground tests. Other activities at the test site have included safety tests of nuclear devices (non-nuclear yield to a small nuclear yield), testing and development of nuclear rocket engines, radiation and dosimetry studies, low-level waste disposal, TRU waste storage, and high-level waste disposal experiements. Sandia National Laboratory also has a test area to the north of the test site.

There are many areas of the NTS contaminated with radioactivity. The contamination in these areas is the result of numerous above ground tests prior to 1963, several series of safety tests where actual or simulated nuclear devices were detonated, Plowshare nuclear cratering experiments, as well as tens of underground nuclear tests that have vented radioactive effluent. The last significant venting of an underground test was Baneberry in December of 1970. There are also a number of sites for storage and disposal of waste.

In 1963 the U.S. signed a treaty banning nuclear weapons tests in the atmosphere, in outer space, and underwater. Prior to 1963, the U.S. conducted numerous surface and safety tests at NTS. Nuclear tests produce a high enough energy yield that there is minimal contamination from uranium and plutonium close to the point of detonation. The primary contamination from the nuclear tests is from fission products and, sometimes, activation products.

Safety shots generally had a zero or minimal nuclear yield. The objective of the saftety tests was usually to determine whether the weapons design was such as to prevent an accidental nuclear detonation (e.g., if part of the conventional explosive detonated would the device go nuclear?). Therefore the fissil material is often dispersed around the shot area, leaving high concentrations of plutonium and/or uranium. Some safety shots used depleted uranium, but other tests used actual weapons.

Information on selected facilities, areas of contamination, and waste disposal or storage sites is summarized in Table 3-34 (ERDA77d).

The DOE plans to consolidate wastes from many of the inactive sites at NTS at a common site (ERDA77d). Also, as of 1974 TRU wastes (greater than 10 nCi/g of transuranics) were separated from LLW and stored as retrievable wastes, at a single location.

TABLE 3-34

NEVADA TEST SITE SUMMARY

Activities	D&D Waste Volume (m^3)	D&D Waste Activity (Ci)
NRDS Nuclear Rocket Tests - 14 fenced contaminated areas		
(Area 25) Engine Maintenance Assembly Bldg - EMAD Reactor Maint. Assembly Bldg - RMAD (NRDS facility is on the SFMP list; however, EMAD is and will probably continue to be used for HLW program)		
Ponds for tunnel drainage water (contaminated with tritium (uCi/l)).		
Drilled reentry holes for underground tests, contaminated drilling mud, and samples of nuclear debris from cavity. In the past radioactive debris was often buried on location--now returned to drill hole or other proper disposal.		
Pu Contamination Related to Safety and Pu Tests (ERDA77d):		
Double Track (0.30 km^2)		5 Pu
Clean Slate I (0.22 km^2)		5 Pu
Clean Slate II (0.79 km^2)		29 Pu
Clean Slate III 1.36 km^2)		30 Pu
Area 13 (3.63 km^2)		44 Pu
Area 11 (4.8 km^2)		39 Pu
GMX (0.24 km^2)		3 Pu
Super Kukla (Fast Burst Reactor)		
Wastes from NRDS, Pluto, Super Kukla		
Wastes from reentry into tunnels after shots. (Highly contaminated waste is sealed in unused drifts).		
Radioactive Waste Storage Sites		
27 Inactive Sites: Mostly LLW; i.e., heavy equipment, metal towers and misc. iron debris from surface tests. Plans are to consolidate sites.		
6 Inactive: Partially cased drilled holes, sealed with steel plates or concrete. Contain core samples from reentry.	100	

TABLE 3-34 (CONT)

Activities		D&D Waste	
		Volume (m^3)	Activity (Ci)
Active Storage or Disposal			
Area 8 Cavity (U8d) low level liquid waste pumped into cavity from previous test.			
Area 5 Waste Management Site			
LLW (some classified)			
TRU storage (NRC79)		184	1060
Area 25 Waste Management Site			
Area 3 U3ax crater from previous test			
Horn Silver, Mine, Area 26 (Project Pluto Wastes)			
Subtotal Buried Waste Management Wastes (NRC79) 2.4x10^4 m^3; 3.8x10^6 Ci			
R-MAD Bldg (former test equip), U3fi (unused 180 cm diameter drill hole used for classified waste). 10 seepage basins (mine dewatering and decontam. operations). 3 leach fields		See SFMP Program	
Plowshare Cratering Shots			
Sulky Dec 64, didn't crater	(1kt)		
Palanquin, April 65	(4kt)		
Sedan, July 62	(100kt)		
Cabriolet, Jan 68	(2kt)		
Buggy, March 68 (5 devices total)	(5kt)		
Schooner, Dec 68	(35kt)		
84 Above Ground tests 1951-1962 (Ve73)			
About 500 underground tests (Ve73), Conservative estimate median yield 50 kt fission (Ca79)			
Subtotal Stored TRU Wastes		184	1060
Subtotal Contaminated Soil (see text)		1x10^6	155 Pu
Subtotal, cavities of underground tests		3x10^8	5x10^6

Most nuclear tests have been conducted at NTS. However, some special purpose tests have been conducted at other locations. The Spartan Missile device was tested in Alaska because of projected maximum nuclear yield limitations for NTS. Other off-site tests have included natural gas stimulation experiments.

The locations in the U.S., off the NTS, where tests were conducted are identified in Table 3-35. Nuclear testing in the South Pacific is not included in this document.

Records indicate there have been more than 500 underground nuclear tests at NTS (Ve73 and Ca79). This is based on the reported tests and recognition that there are unannounced tests. Ca79 gives data indicating an average yield of about 80 kt* for the underground tests (range about 0 to 1000 kt. Assuming a 0.5 fission/fusion ratio gives an estimated average fission yield of 40 kt. Based on this, it is estimated that there is an average of 2.6 kCi of Sr-90, 7.6 kCi Cs-137 and about 3 kg or about 200 Ci of plutonium (incomplete fission) associated with each test cavity. Tritium and other fission products are also present in the debris. Assuming that this material is dispersed into a cavity with a 50 m radius, there is a contaminated volume of 5×10^5 m^3 per test (Te68). A curie content for the tests in Table 3-35 can be approximated by scaling linearly from the above numbers, except for the two high yield shots at Amchitka. Those shots require additional considerations of fission to fission ratio.

The estimate of total volume of soil contaminated with plutonium is

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* 1 kt - 1 kiloton is an explosive force equal to 2×10^6 pounds of TNT.

TABLE 3-35

NUCLEAR TESTS OFF THE NEVADA TEST SITE
Sources: Ca77 and Ca79

Name	Location	Yield (Kiloton)	Date	Project
Long Shot	Amchitka, Alaska	80	Oct 65	Detection of Nuclear Tests
Milrow	Amchitka, Alaska	1,000	Oct 69	Calibration Seismic
Cannikan	Amchitka, Alaska	5,500	Nov 71	Spartan Missile
Salmon	Hattisburg, Miss	5	Oct 64	Detection of Nuclear Tests
Sterling	Hattisburg, Miss	0.4	Dec 66	Detection of Nuclear Tests
Gnome	Carlsbad, New Mexico	3	Dec 61	Plowshare
Shoal	Fallon, Nevada	12	Oct 63	Detection of Nuclear Tests
Faultless	Hot Creek Vy, Nevada	1,000	Jan 68	Calibration Seismic
Gasbuggy	Farmington, New Mexico	29	Dec 67	Plowshare
Rulison	Rulison, Colorado	40	Sep 69	Plowshare
Rio Blanco (3 devices)	Rio Blanco, Colorado	3x30	May 73	Plowshare
Trinity	New Mexico	19	Jul 45	First Nuclear Test

based on the areas given in Table 3-34 for safety and Pu tests and an average depth of 10 cm. Plutonium is generally on the surface; however, in many of the areas it has been mixed to a considerable depth by various site activities.

Subtotals for the various sources of waste are given in Table 3-34. For the nuclear cavities only the activity from to Sr-90 and Cs-137 is given. There will also be about 60 Ci of Zr-93 ($9.5X10^5$ year half-life) present in the 500 cavities. Large amounts of surface and buried contamination are not included because of the lack of information. The waste volumes in the nuclear cavities should not be classed as D&D wastes, because it is not realistic to consider excavating the cavities.

The Pantex Plant is located in Carson County, Texas, northeast of Amarillo, on U.S. Highway 60. The Pantex Plant was built in 1942 to produce conventional bombs and shells. The plant was deactiviated after World War II. In 1951, the Atomic Energy Commission reactivated the plant as an explosives components plant. The current facility occupies 37 km^2 of the former 60 km^2 Pantex Ordnance Plant Reservation. Mason and Hangar-Silas Mason Co., Inc. became the operating contrator in 1956.

The basic mission of the plant is to fabricate high explosives and other components, and perform final assembly of nuclear weapons. The plant also provides components and performs final assembly testing of units for DOE and DOD testing and training programs. In addition, they perform laboratory tests on stockpiled weapons and perform modification and repair work (DOE79c).

One portion of the plant is devoted to fabrication of high explosives

(HE) components and weapon assembly/disassembly operations. Another portion of the plant is devoted to HE development work. This includes an area where items are test fired. A third plant area is used for landfill disposal. A dry lake in the east central area of the site is used for retention of the plant's treated sewage effluent and liquid waste. LLW and TRU wastes are handled in underground retrieval storage facilities consisting of subsurface concrete cylinders or silos (approximately 20 feet deep and 6 feet in diameter) in a 0.014 km^2 (3.5 acres) area of Zone 4. The stored volume of the LLW is 100 m^3, with an activity of 10^3 Ci. A trench in the same area has been used to store 27 m^3 (10^3 Ci) of LLW. The trench is not being used now. Transuranic waste is stored in underground silos. The volume is 33 m^3, and the activity is very low. TRU was also stored (retrievable) in the trench (NRC79).

The above information is insufficient to project D&D wastes.

The Pinellas Plant, in St. Petersburg, Florida, was built in 1956. The facility was to develop and produce neutron generators for nuclear weapons initiation (i.e., a source to start reaction). The plant is owned by DOE, and operated by the Neutron Devices Department of General Electric Co. (DOE79c).

The plant site area is 0.39 km^2. The primary building (Building 100) has a floor area of 0.032 km^2; eight other buildings (No. 200 to 900) have a total floor area of 450 m^2. There are two lakes on site which have a volume of 22,000 m^3. They are used for liquid effluent (ERDA77g).

The facility produces miniaturized neutron generators and electronic assemblies for nuclear weapons and weapons testing. Products include medium power radioisotopic thermoelectric generators and neutron measurement devices.

NRC79 does not list Pinellas as disposing of or storing LLW or TRU waste on site. ERDA77g does not mention stored or disposed waste, but indicates effluents of tritium, HTO, and Kr-85. Ha75 discusses waste water management at the facility but does not discuss radioactivity in the water. The conclusion drawn from these references is that there should only be minimal contamination at this facility.

The Rocky Flats Plant is located 16 miles northwest of downtown Denver, equidistant from Boulder, Golden and Arvada, Colorado. The reservation covers an area of about 26 km^2, and has about 100 structures with total building floor space of about 0.20 km^2. This facility is owned by DOE and operated under the direction of the DOE Albuquerque Operations Office. The plant was established in 1952 with Dow Chemical as the initial operator. In 1975, Atomics International, a Division of Rockwell International, replaced Dow as the operating contractor. The plant is a key facility for the production of nuclear components. Most of the work is directly related to national defense. The northern half of the plant is involved in processing plutonium and general waste treatment. The southern half houses uranium, beryllium and stainless steel component fabrication operations.

The Rocky Flats Plant includes major facilities for the fabrication, assembly, and quality testing of radioactive and nonradioactive components for nuclear weapons, chemical processing and process waste treatment, and research and development.

Past waste disposal methods and locations are listed below (NRC79):

- Oil Burning Pits (Pit 1, 1957; Pit 2, 1956 and 1961-1965). Oil containing depleted uranium was burned and the residue covered with fill. Pit 2 was excavated in 1978 and contaminated residues removed. These pits are designated as locations 1 and 2, respectively.

- Two sets of trenches, similar in design to sanitary landfill trenches, were excavated in the periods 1954-1962 (T-1) and 1954-1968 (T-2 through T-8). The primary contaminant in trench T-1 was depleted uranium. Trenches T-2 through T-8 contain sanitary sewage sludge and flattened empty drums. The larger pits contain a larger fraction of plutonium than the smaller pits. All trenches were closed and covered with a layer of top soil approximately two feet thick. Trench T-1 is known as location 3, and the other trenches are called location 4.

- Asphalt and Soil Disposal Areas (1969 and 1972). This is a fill area covered by two to three feet of soil and contains low levels of plutonium. These areas are called location 5.

- Incinerator Ash Pits, I-1 through I-4 (1952-1968). These pits were dug to house ash residues from plant incineration of general combustible waste. About 100 grams of depleted uranium are present. These pits are known as location 6.

- Sanitary Landfills (original and current). The primary contaminant in the varied waste products is depleted uranium. Contaminated sewage sludge containing a total of 1 to 1.5 millicuries of alpha acitivty is buried at the current landfill. Twenty kilograms of depleted uranium is buried in the original landfill. The original landfill is location 7. The current landfill is location 8.

- South Walnut Creek. This area contains low levels of plutonium and uranium depositied there from process liquid waste treatment outfall. This area is designated location 9.

- Area 903 (1958-1967). This area was used to store drums of plutonium-contaminated oil and became contaminated when the drums about $3.5X10^4$ m^2. The estimated volume of waste in locations 1 and 3 through 9 is $4X10^3$ m^3. The curie content is low.

These locations are no longer receiving waste.

Currently there is no active disposal of radioactive wastes at Rocky Flats. DOE considers these burial grounds and contaminated soils to be contaminated property that will eventually be removed as part of site decommissioning. Radioactive wastes are prepared for storage at the Idaho National Engineering Laboratory (TRU wastes) or for disposal at the Nevada Test Site (non-TRU wastes) (NRC79).

There have been several fires in plutonium processing facilities and accidental releases of plutonium from the Rocky Flats plants over the years, in addition to normal effluent releases. However, very little material has been released through the fires. Over 90 percent of the envioronmental release (excluding seepage and settling ponds and burials) are attributed to leaks from drums stored between 1959 and 1969 (Kr76 and DOE80h).

Krey et al. (Kr76) estimate a total on-site and off-site inventory of 11 Ci of plutonium (mostly Pu-239/240). Off-site concentrations all appear to be below the draft EPA transuranic guidance of 0.2 $\mu Ci/m^2$ (EPA77, EPA77a, DOE80h).

The on-site inventory of about 8.6 Ci covers an area of about 6 km^2. Roughly one third on this area is above the propsed EPA guidance. DOE has taken steps to prevent additional spread of the on-site contamination and remove the highest levels. The above area is considerable larger than the previously discussed Location 10 (only $3.53X10^4$ m^2).

There is some uncertainty in the actual inventory numbers since many investigators have obtained higher inventory estimates from environmental results than Rocky Flats records estimate for the inventory in the drums (about 8 Ci).

Prior to 1973 the plant used a series of waste treatment ponds and discharged treated effluent to South Walnut Creek. In 1973, the plant improved the process procedures and initiated a program to prevent future discharges (DOE80h).

In 1973 the plutonium inventory in the sediments of the 4 B-ponds (unlined) was 3 Ci and it was suspected that several additional curies were in the sediments above Pond B-1. The total capacity of the ponds was about 1000 m^3 (DOE80h). Assuming a 1.5 m pond depth and 1 m of sediment in the bottom, this equates to a sediment volume of about 700 m^3. Samples from sediment in the A Ponds indicated plutonium concentration at or below 10 pCi/g(DOE80b).

There are also several on-site solar evaporation ponds used for process wastes. It is estimated that the volume of contaminated soil under these ponds (leaks in liners) is at least 200 m^3.

There are other areas of soil contaminated with plutonium around process buildings and from discharge of laundry wastes which contained low levels of plutonium.

The radiological contamination at Rocky Flats is primarily plutonium and uranium. Different grades of enriched uranium are used for various products, however, much of the uranium is depleted in U-235. Rocky Flats also handles gram and milligram quantities of Curium-244, Np-237, Th-228, and U-233 (DOE80h).

The Rocky Flats Plant generally does not work with tritium in process materials. However, in mid-April of 1973 the plant received plutonium scrap contaminated with up to 2000 Ci of tritium. It wasn't until the state detected tritium in the plant discharge that the presence of the tritium was known.

It is concluded that, due to the nature of the operation and processing of scrap material from other laboratories, radionuclides other than plutonium, americum and uranium may be present at Rocky Flats.

There is very little detail available on the Rocky Flats facilities (DOE80h). The functions of the facilities; e.g., metallurgy sampling, casting, machinery, reprocessing, coating, etc., are mentioned, but little information is given on the actual facilities (DOE80h, DOE79c). Therefore D&D estimates are based on using ratios of floor space to process equipment and resulting D&D wastes. Elder and Blahnik (El80) indicate a ratio of 1 m^3 of D&D waste per 6 m^2 of floor space for uranium fabrication plants. A similar ratio of 1:6 for uranium conversion plants is reported by El81a. Appendix B f this report estimates a ratio of 1:1 for selected fuel reprocessing operations. Given the nature of the Rocky Flats operation and working with plutonium and beryllium and other hazardous metals (chromium, molybdenum, etc), a ratio of 1 m^3 of waste per 2 m^2 floor space is used.

Therefore, based on the 0.20 km^2 of plant floor space and assuming 60 percent (40 percent fabricator and processing, 20 percent labs and testing, DOE80h), of the space is used for contamination related operations, we estimate a volume of 6×10^4 m^3 D&D contaminated wastes. Given the classified nature of the facility and the hazardous material, it is assumed most of this will result in waste rather than be recycled. The specific activity of wastes from the reference uranium conversion and fuel fabrication plant (E180 and E181a) vary from 4 to 0.03 kg of uranium/m^3, respectively. Using the lower value, and a specific activity of 0.06 Ci Pu-239/g gives an estimate of about 2 Ci of Pu per m^3. The specific activity of Am-241 is 3.4 Ci/g. If Am-241 was present in similar mass quantities, the amount of activity would be much greater.

The above estimates are summarized in Table 3-36.

Physical Research Facilities - There are four DOE physical research laboratories (DOE79c):

Bates Linear Accelerator Facility, Middletown, Massachusetts
Fermi National Accelerator Laboratory, Batavia, Illinois
Notre Dame Radiation Laboratory, South Bend, Indiana
Stanford Linear Accelerator Center, Palo Alto, California

Notre Dame is a leader in research on the mechanisms of chemical changes following the absorption of high energy radiation by any state of matter. The other three facilities are accelerator laboratories. The primary ionizing radiation instruments at all of these laboratories are accelerators, with the exception of Co-60 sources at Notre Dame.

The pertinent features of these facilities are summarized in Table 3-37 (DOE79c). These facilities are listed in this section to give a complete composite list of DOE facilities. Accelerators are evaluated in

TABLE 3-36

SUMMARY OF ROCKY FLATS PLANTS WASTE

Material	Volume (m^3)	Activity
Processing Equipment	6×10^4	
Assume: ½ Contaminated with Uranium		1000 kg U
½ Contaminated with Pu		50,000 Ci
Ponds		
Solar Evaporation Pond	200	
B Ponds (4)	700	5
Locations and 3 to 9	4000	Low
Contaminated Soil (assume 1/3 of $6 km^2$, depth 5cm)	10^5	5
Other Areas	---	
Totals (numbers are rounded)*	2×10^5	5×10^4 Ci Pu 1000kg U (0.33 Ci U-238)

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* Much of the process equipment and B Pond material would be TRU waste. For the DOE facilities summary one-half the total volume and essentially all of the activity were assumed to be TRU wastes.

TABLE 3-37

PHYSICAL RESEARCH FACILITIES

Facility	Operator	Major Equipment	Year of Startup
Bates	MIT	400 MeV Electron Linear Accel. (5200 Beam hours in 1978). Electron Scattering Spectrometer	1972
Fermi	University Research Assoc., Inc. (53 universities)	800 GeV Proton Synchrotron (Being increased to 1000 GeV) (Linac, probably part of Synch) DOE79a reports the present of about 170 m^3 low level scrap (activation) and waste on site.	1976
Notre Dame	University of Notre Dame	Linear Accelerator Van de Graaff Van de Graaff - ESR spectrometer Co-60 source(s)	
Stanford	Stanford University	22 GeV Linear Accelerator Several magnetic spectrometers Electron-positron colliding-beam storage ring (4 GeV) 40 in bubble and streamer chambers. Position Electron Project, PEP (storage ring, 18 GeV). DOE79a gives an estimate of 10 Ci of residual activity throughout the machine.	

Chapter 10.

Other DOE Related Facilities - This category includes several one-of-a-kind facilities, facilities at which no significant contamination is expected and facilities where there is some question concerning DOE involvement or responsibility. The primary purpose of this discussion is to document the presence of these facilities. Some of the sites, even though they may be active today, are listed in the DOE remedial programs (e.g., Shippingport reactor is in the SFMP program, DOE82a). Involvement with SFMP is indicated with a parenthetical insert after the title.

- The New Brunswick Laboratory (SFMP) services as the U.S. Government nuclear materials measurements laboratory. It specializes in the analytical chemistry of materials and focuses on the nuclear materials safeguards program. The laboratory was moved from New Brunswick, New Jersey to the Argonne National Laboratory site in Illinois in 1977 (DOE79c). DOE82a gives an estimate for D&D wastes for the New Jersey site of 120 m^3 of soil and rubble of LLW. No TRU waste is expected. These values should provide a fair estimate for D&D of the new site.

- The Princeton Plasma Physics Laboratory is located at the James Forrestal Research Center, in princeton, New Jersey. Thermonuclear applications are the laboratories major speciality. It is one of the four major controlled thermonuclear research facilities supported by DOE. The laboratory is an integral part of Princeton University (DOE79c). This facility is not listed by NRC79 nor is it listed in the annual DOE environment report, ERDA77g. It is assumed any contamination is primarily limited to tritium.

- Atomics International (SFMP) has two or more sites in the Los Angeles, California area. The Santa Susana Field Laboratory (SSFL) site has several DOE activities (ERDA77g) many, if not all, of which are surplus and included in the SFMP program (DOE81c, DOE82a). ERDA77g reports environmental surveillance results. The activities identified by ERDA77g, radioactive waste processing and storage and fabrication of plutonium/uranium fuel pins (building 5S) appear to be included in the SFMP list (DOE81c, DOE82a). The SFMP list also includes the Sodium Reactor and SNAP 8.

- The Battelle Columbus Laboratory (BCL), located in Columbus, Ohio, is owned and operated by Battelle Memorial Institute, a non-profit organization. BCL has two sites; King Avenue ($0.04 km^2$) and West Jefferson, Nuclear Science area ($0.04 km^2$). BCL is listed by ERDA77g as a "DOE facility". Earlier reports on the SFMP program (DOE81c) also listed several of the BCL activities in the SFMP program (research reactor and metallurgical facilities). However, the current SFMP program list (see Section 3.3.3 and DOE82a) does not include these facilities. BCL has done work for DOE; however, it is a private lab, not a DOE facility.*

- The Center for Energy and Environmental Research (SFMP), formerly the Puerto Rico Nuclear Center, is operated by the University of Puerto Rico. The center has several sites with a total area of 1 km^2. The sites include a lab in Mayaguez (about 0.1 km^2), the former BONUS reactor site at Pt. Higuero, and San Juan.

  Most of the radiation related facilities have been decommissioned or are on the SFMP list (DOE81c, DOE82a). The BONUS reactor (16.3 Mwe), which operated from 1964 to 1968, has been "entombed" (Er79). The fuel and major contaminated equipment were removed and the remaining contaminated material placed inside the biological shield (DOE81c). The reactor has been removed from the most recent program list, but is retained within the program (DOE82a). Mayaguez includes a research reactor which is on the SFMP list (DOE81c), a small training reactor, a graphite critical assembly, a 200 keV particle accelerator, and a 5000Ci Co-60 source. The D&D waste volumes for the identified facilities not on the SFMP list are projected to be about $50m^3$. It is assumed the Co-60 source will be salvaged.

- The Comparative Animal Research Laboratory is located on the Oak Ridge site and operated by University of Tennessee. The laboratory is included in the Oak Ridge facility discussion.

- The Clinch River Breeder Reactor is a reactor demonstration project, under the Oak Ridge Operations Office, located on the Oak Ridge Site.

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* Personal communication with David Doerge, United Nuclear Incorporated, April 22, 1982.

- The DOE Environmental Measurements Laboratory is located in New York City, New York. The lab is owned and staffed by DOE. The lab specializes in low-level measurements and any volumes of D&D waste would be small (e.g., a concrete slab for radon exhalation measurements) (DOE79c).

- DOE Mineral Rights: DOE has mineral rights on 38 parcels of land totalling 84 km^2 in the Uravan Mineral Belt in southeastern Colorado, 5 parcels containing 11 km^2 in Utah, and 3 parcels containing 6 km^2 in New Mexico. Many of the tracts are under lease to uranium ore producers and are being developed or are in production. There are about 150 mine waste dumps containing about 10^6 MT of subore material (roughly 0.02 percent U_3O_8), covering an area of about 0.2 km^2 on these lands. About 10 percent of the material contains 0.02 to 0.08 percent uranium. The rest is about 0.02 percent or less. DOE has a program for stabilizing the old mine wastes (generated prior to 1974) and is requiring operators to stabilize future ones (DOE79a). Most of this material will probably by stabilized in place.

- The Franklin McLean Memorial Research Institute, formerly the Argonne Cancer Research Hospital, is operated by the University of Chicago for the DOE. The institute occupies an eight story building on a site leased to DOE by the university. The activities include a broad range of biochemical studies. Primary radiation related facilities include three high-energy radiation therapy machines, a medical cyclotron, and a portable Rho-Gamma III Anger camera (DOE79c). The available literature does not indicate any significant areas of contamination.

- The Grand Junction Office is the area office of DOE in Grand Junction, Colorado. There are about 30,000 MT of uranium tailings buried in a 0.4 ha area in the compound. The estimated concentration is 840 pCi/g, for a total inventory of about 25 Ci of Th-230, Ra-226 and associated ratio nuclides. The tailings have been covered with soil. The site is not listed in any of the DOE remedial programs.

- The Monticello Uranium Mill (SFMP) is an inactive uranium mill site and tailings pile owned by DOE. The pile covers an area of about 0.16 km^2 containing about 900,000 MT of tailings, with a concentration of 840 pCi/g (DOE79a). This site is listed in the SFMP program (DOE82a).

- The Inhalation Toxicology Research Institute is owned by DOE and operated by Lovelace Biomedical and Environmental Research Institute. The institute is located on Kirkland Air Force Base near Albuquerque, New Mexico. The labs programs, which began in 1960, include evaluating the uptake and health effects from inhalation of radiological particulate and gaseous material. Non-radiological materials are also studied. The institue has facilities for preparing aerosols and inhalation exposure chambers (DOE79c). The existing contamination and D&D wastes are expected to be small.

- The Laboratory for Energy Related Health Research (LERHR) is in Davis, California, on the campus of the University of California at Davis. The laboratory is associated with the School of Veterinary Medicine and is operated by the university for DOE. Since its beginning in 1951, the main focus of the laboratory has been long-term low-level effects of ionizing radiation and fossil fuel energy-related effluents. Major research objectives include chronic effects from low levels of Sr-90 and I-129. The laboratory complex is on an 0.06 km^2 site with 5000 m^2 of buildings. The primary radiation facilities appear to be exposure chambers, laboratories, and a gamma ray field (DOE79c). The SFMP (DOE82a) identifies surplus waste facilities at the U.C. Davis Radiobiology Laboratory. It appears this laboratory is part of the LERHA facilities (DOE81c). The presence of significant radiological contamination (other than that listed under SFMP) is not indicated.

- The Laboratory of Nuclear Medicine and Radiation Biology is located on the Los Angeles campus of the University of California. The laboratory has operated under contract to the government (DOE) for over 30 years. It focuses on energy related biomedical and environmental problems. Located in the UCLA Center for Health Sciences, it has about 7000 m^2 of laboratory space. Major facilities include a cyclotron (DOE79c). The presence of significant radiological contamination is not indicated (DOE79c).

- The Laboratory of Radiobiology is located at U.C. San Francisco. The DOE provides the primary support for this laboratory which is a research unit of the U.C. School of Medicine. The focus of the program is developing methods for teratogenic and mutagenic assessment of physical and chemical agents. The presence of significant radiological contamination is not indicated (DOE79c).

- The Michigan State University DOE Plant Research Laboratory is located on the University of Michigan campus and is operated by the university for DOE. Established in 1964, the lab provides a center for modern experimental plant biology (DOE79c). The facility does not appear to have radiation related facilities.

- The Niagara Falls Storage Site (SFMP), in Lewiston, New York, is part of the Lake Ontario Works and has also been known as the Boron Isotope Production Plant (DOE79a). The site was used for storage of residuals from ores processed at other locations. Most of the residuals are owned by African Metals Corp. Some are owned by the U.S. Some of the materials are stored in buildings; others are stored outside. Reported estimates of the volume range from about 1.2×10^3 m^3 (DOE79a) to 7.8×10^5 m^3 (NRC79).

- Power Reactors: Several government supported reactors have been decommissioned. The Elk River Reactor in Minn. (Docket 115-1) was dismantled and Federal control was terminated (Er79). The Piqua, Reactor in Ohio (Docket 115-2) was deactivated by Atomic International (He75). The site was purchased by the Federal Government, and leased to the city of Piqua. The fuel and removable core components and other radioactive materials were shipped off site for disposal. The organic coolant was burned. The reactor vessel, which contained about 2.6×10^5 Ci of activity (primarily activation products) was sealed. The reactor building was retained for use as a warehouse (He75). The Hallam Neb., (Docket 115-3) and Bonus (Puerto Rico, Docket 115-4) reactors have also been decommissioned. Er79 lists the last three reactors as entombed; however, safestore may be a better category. The DOE is monitoring all of these sites.

- The Radiobiology Laboratory is adjacent to the College of Medicine, University of Utah. The university operates it for the DOE. The primary objective of the lab is to conduct studies on the deposition, translocation, retention, and acute and chronic effects of radionuclides (primarily alpha emitters) in experimental animals (DOE79c). Only minimal levels of contamination and D&D wastes are expected in the facility.

- The Shippingport Atomic Power Station (SFMP) is in Shippingport, Pennsylvania. The reactor, 236 Mwe, was built for development and demonstration purposes by the AEC and Duquesne Light Company. A light breeder reactor core was installed in 1976. The reactor is to be shut down and decommissioned in 1985 (ERDA79g, DOE82a).

- SNAP Power Sources have been used in several places in the U.S. and around the world. Usually these are high activity sources of Sr-90 or Pu-238 and thermoelectric generators to produce electricity. A list of locations is not provided, but it is known that two SNAPs were placed in the Amchitka, Alaska, area for the nuclear testing program* and in Antarctica for a Navy program. Other locations have not been identified. If the devices functioned properly there should be no contamination. These devices were developed and placed under DOE (or its predecessor's) sponsorship.

- The University of Rochester Biomedical Laboratory is operated for DOE by the University of Rochester. The lab, which is an integral part of the University Medical Center, is located adjacent to the main campus. The DOE supplies about 6000 m^2 of lab space and the university about 12,000 m^2. The lab was established in 1944 as part of the Manhattan Project. Its programs are oriented toward toxic materials (including radiation) associated with energy production. Laboratory facilities include gamma ray and x-ray exposure facilities, and aersol generating and analysis equipment (DOE79c). Available information does not indicate significant levels of contamination (ERDA77g, DOE79c).

- The Vallecitos Nuclear Center (SFMP) is a General Electric facility. The Advanced Fuels Laboratory, a DOE dedicated facility since 1975, was operated for DOE. The DOE facilities are on the SFMP program list (DOE82a).

- The Weldon Spring Production Center (SFMP), in Weldon Spring, Missouri, which was formerly operated by Mallinckrodt Chemical, contains residuals from domestic and foreign ores. Reported estimates of the residuals range from 1.7×10^5 m^3 (DOE79a) to 6×10^6 m^3 (NRC79) in 4 pits. A quarry contains about 1.5×10^6 m^3 of thorium residuals. The site is in the SFMP program (DOE82a).

- The Waste Isolation Pilot Plant is proposed for pilot plant disposal of high-level waste in a bedded salt formation near Carlsbad, New Mexico (DOE80e).

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* Personal communication with C. Hendricks, Don Hendricks and Associates, April 17, 1982.

There were several DOE related UF_6 conversion facilities. These were at Fernald, Ohio (National Lead), Weldon Spring (Mallinckrodt Chemical, on SFMP), Portsmouth, Oak Ridge, and Paducah. All of these facilities, except for a small plant at Portsmouth, are shut down or converted to other uses (E181a).

3.3.5.4 D&D Procedures

The basic alternatives for D&D given in Section 2.4.1 are DECON, SAFSTOR, ENTOMB. A common alternative used by many DOE facilities is a variation of SAFSTOR. When a program activity ends, the facility is mothballed (i.e., put in SAFSTOR) until there is a program need for the facility. When a need is found, the facility is decontaminated to the required level, modified as needed, and used. Hence, many facilities on the various DOE laboratory reservations have been deactivated from one program, partially cleaned, and reused in several additional programs without D&D to meet unrestricted use.

Most of the DOE facilities are on large sites with controlled access (DOE79c, ERDA77g). Therefore, the de facto use of SAFSTOR or mothballing has allowed considerable flexibility.

Recently, as the number of surplus facilities has increased as a result of program changes and facilities becoming obsolete, individual DOE laboratories have developed positive D&D programs (ERDA77b, Me78) and DOE has developed an overall D&D program (DOE80d, DOE80f, DOE81c, DOE82a). The incentive for developing positive plans has come partially from the focus on inactive uranium mill tailings sites and the resulting Uranium Mill

Tailings Radiation Control Act of 1978 (PL78) and the large number of facilities that are reaching the end of their useful life expectency of 30 to 40 years of age. Specific D&D plans depend on the type of activity that is being decommissioned, the program office doing the work, the future use of the area (e.g., government reservation or return to unrestricted public use), and budget restraints.

Present planning for DOE facilities attempts to foresee surplus facilities and therefore develop plans for future uses or decommissioning prior to the actual time of shutdown. For example, the Shippingport Reactor, which is operating and will continue operating until about 1985, is on the surplus list (DOE81c, DOE82a).

The basic sequence of events is:

- Identify, if possible anticipate, that a facility is surplus.
- Mothball or put the facility in SAFSTOR.
- Provide continued environmental surveillance for the facility to ensure protection of health and safety (DOE80g).
- If there is no anticipated use of the facility, place it in the SFMP program for D&D (DOE81c and DOE82a).

The actual or expected D&D of various types of facilities has been described by: Wa79, production reactors; El80, fuel fabrication plant; El81a, UF_6 conversion plant; and Ko82 for research and test reactors. An unresolved issue appears to be the removal of buried radioactive wastes. Essentially the trend seems to be to leave wastes that can be defined as properly disposed LLW, but to excavate seepage ponds, cribs, TRU waste, etc. (Wa79, E180, E181a, Ko82). However, there does not appear to be specific written guidance and implementation appears to depend on the intended disposition of the site and possible the agency or laboratory taking the action (NRC79, DOE78b, ERDA75).

Ko82 indicates that even for research and test reactors, DECON is the most likely decommissioning alternative. It requires a high initial outlay of funds, but overall it is the cost effective alternative. Furthermore, people associated with the operation of the facility will still be available to guide the D&D if it is done soon after facility use rather than a generation or two later. The proper choice of D&D efforts is site specific. The decision depends on numerous factors, including availability of funds, cost of providing continued security and surveillance, and the rate of decay of contamination products.

3.3.5.5 Characterization of Wastes from D&D

The existing contamination, and therefore D&D wastes from active facilities, ranges from concentrations that give exposure rates of hundreds of R/hr to rates of mR/h. The radionuclides range from short-lived fission products to short and long-lived activation products, long-lived fission products and transuranics and special nuclear materials. The large national laboratories can be expected to have contaminants that encompass the full spectrum of radionuclides.

The residual contamination associated with reactor materials (primarily activation products) will normally be part of the material matrix. Residual fission products will be surface contamination, but will also be imbedded in porous and corroded materials.

The chemical form will also include the whole spectrum. Uranium will often be in solution as a nitrate. Uranium surface contamination may be UO_2, UO_3, U_3O_8, or a diuranate (e.g., ammonium, etc.). A large amount of the contamination in UF_6 conversion plants is classified as U_3O_8 (E181a), but much of this may be sodium diuranate, which is much more soluble than UO_2 or U_3O_8.

The estimated D&D volumes are only rough projections, but it is evident from the estimates for the various sites that the major volume of material is usually contaminated soil and/or structural material. For reactors the biological shield often contributes a large amount of material. For structures, the heating and ventillation system can be a major source of waste volume. Depending on the system design, waste tanks, retention ponds, and waste transit systems (culverts, ditches, piplines) are a major source of waste.

The radioactivity is usually not distributed throughout the waste. Although soil may be the largest contributor to waste volume, the amount of activity associated with the soil is usually relatively small (in curie quantities). For reactors the majority of the activity, after defueling and initial cleanout, is activation products in the reactor vessel, control rods, and core support structure. It is difficult to make accurate general statements about the important of the various radionuclides. Iron-55 and Ni-63 are produced in fairly large quantities and have fairly long half-lives. However, their decay schemes are such (see Appendix D) that they are not an external radiation hazard. Zinc-65 is important immediately after shutdow (its decay produces a significant gamma exposure) but its half-life is ess than one year. For gamma exposure, Co-60 is often the most importanlong-lived radionuclide present, but Zr-93 (1.5×10^6 yr half-life, also fission product) and Nb-94 (2×10^4 yr) can become important after about years, depending on the structural materials. For a given integral neun flux the production of significant activation products in aluminum is h less than for stainless steel (Ko82). For the reference test reactorppendix A) the greatest contributor to the activation products is trim in the beryllium. When the emphasis is placed on nuclides with half-li greater than 30 years, the primary radionuclides are Zr-93, Nb-94 and Ni Available information makes it difficult to estimate the significance transuranics.

3.3.5.6 Resl Materials

The poslity of recycling materials depends on the intent of the D&D action.t Idaho National Engineering Laboratory tens of reactor facilities hbeen used for new reactors. At other facilities, a change in programs completing a program has resulted in partially decontaminating aility and reusing it (Mo75). Overall, there appears to be limited emph on decontamination of materials to allow recycle (Ko82, El80 and El; rather, the emphasis is on minimizing the amount of radioactive .

Most of activity associated with reactor materials is activation products imbd in the material. Most of the volume is soil and concrete. Billy, these materials cannot be decontaminated.

No atteas been made to identify recyclable materials. Basically, the thrust has been to identify the radioactive waste, assuming the remainder would be left. Furthermore, given the classified nature of many of the activities it is doubtful whether much material would be recycled.

3.3.5.7 Summary of Active DOE Facilities

The Department of Energy active facilities include sites ranging from National Laboratories with diverse programs, through nuclear weapons design, production, and testing facilities to university radiobiology research laboratories. There are more than 40 sites. It is difficult to obtain descriptions of the facilities, and make estimates of D&D wastes. Many of the activities are engaged in national defense classified activities.

Estimates of the D&D wastes from active DOE facilities have been made by using reference facilities and applying engineer judgement. The results are often only order of magnitude estimates, but help characterize the facilities. In many instances the activity from short half-life radionuclides is combined with the activity from long half-life radionuclides. Although the D&D wastes from some activities are probably over estimated, it is believed that it is more likely the overall estimates are too low from having overlooked significant activities or existing contamination.

It is difficult to envision complete DECON of some of the major sites (e.g.) NTS, Hanford, Savannah River), given the large amounts of contamination and its dispersion in the environment. Attempts have been made to identify buried LLW, but it is assumed it will not be exhumed. However, it has been assumed that identified cribs, seepage ponds, and TRU, wastes will be included in D&D.

The total D&D wastes from active DOE facilities estimated to be:

	Volume (m^3)	Activity (Ci)
Low-Level Waste	$4x10^6$	$7X10^6$
Transuranics	$3x10^5$	$8x10^5$

Most of the TRU waste comes from stored waste at INEL and Hanford, and D&D of Rocky Flats. Most of the LLW comes from INEL, Hanford, Savannah River, NTS, and Oak Ridge. A large amount of activity is postulated for Knolls Atomic Power Lab, but this may be a result of using the reference reactor for Naval prototype reactors.

4. DOD-CONTROLLED FACILITIES

The U.S. Department of Defense (DOD) through its Departments of Army, Navy, and Air Force controls a large number of facilities both in and outside the conterminous United States. The Marine Corps is part of the Navy Department and many of its facilities are located with other Navy facilities. The Air National Guard and Army National Guard have limited facilities and are part of the Departments of Air Force and Army respectively.

Additional military facilities are controlled by the Department of Transportation through the U.S. Coast Guard. For simplicity, the facilities of all U.S. military services are included in this chapter.

Military facilities range in size from single buildings to large forts and bases which may cover areas as large as a few million acres. In addition to those facilities presently under military control, others have in past years been declared excess to military needs and transferred to other government agencies or sold to the public. Other facilities such as ammunition plants have been placed on standby to be reactivated later in case of need. This chapter presents a summary and analysis of the major military facilities in the United States.

4.1 STATUS

Military facilities cover a range of functions, including schools, hospitals, training academies, research and development laboratories, proving grounds, bombing and gunnery practice ranges, storage depots, arsenals, air bases, naval bases, missile launch sites, forts, and manufacturing facilities for weapons and ammunition. Some facilities are also used for storage of strategic materials for national stockpiles.

Small quantities of radioactive materials have been used or stored at most military installations in the form of luminous dial watches and compasses as well as in electron tubes and lights in electric equipment. Only a relatively few military installations to date have publicly reported radioactive contamination.

Table 4-1 lists military facilities where radioactive contamination of land, harbors, and buildings or other real property is known to exist or may exist. In some cases the contamination may be very minor (e.g. a small accelerator).

Some of the military facilities such as hospitals, research and development laboratories, and schools will continue in operation for the indefinite future. Typically such facilities generate relatively small quantities of low-level radioactive waste. It is expected that only minor amounts of D&D work will be required upon shutdown of such facilities.

Most of the contamination at military sites is a result of research and development testing of military munitions, testing and operation of military reactors, or accidents (such as nuclear weapons accidents). Sites such as the White Sands Missile Range or the Nellis Air Force Bombing and Gunnery Range which have large land areas contaminated with plutonium and fission products may be prohibitively expensive to decontaminate to levels acceptable for unrestricted use.

Sites which have been contaminated with depleted uranium munitions vary widely in character. Some sites have been contaminated by burning or

TABLE 4-1

U.S. MILITARY SITES WITH POSSIBLE CONTAMINATED FACILITIES

Facility	Type of Contamination
Alaska	
Ft. Greeley	Activation and fission products
Alabama	
Redstone Arsenal, Huntsville	Accelerator
California	
Army Ionizing Radiation Center, Lathrop	Accelerator
Camp Parks	Sr-90 in hot cell
Camp Roberts	Depleted uranium
China Lake Naval Weapons Center	Depleted uranium
Long Beach Naval Shipyard & Base	Activation and fission products
Mare Island Naval Shipyard	Activation and fission products
Naval Electronics Lab., San Diego	Accelerator
Naval Post Graduate School, Monterey	2 Accelerators
Port Hueneme	Activation and fission products
San Diego Naval Base	Activation and fission products
Connecticut	
New London Submarine Base	Activation and fission products
District of Columbia	
Naval Research Lab	13 Accelerators
Naval Research Lab, Reactor	Activation and fission products
Walter Reed Research Reactor	Activation and fission products
Florida	
Eglin Air Force Base	Depleted uranium
Hawaii	
Pearl Harbor Naval Shipyard and Submarine Base	Activation and fission products
Indiana	
Crane Naval Weapons Support Center	Thorium
Jeffersonville Quartermaster Depot	Zircon sands
Iowa	
Iowa Army Ammunition Plant (Burlington)	Depleted uranium
Maryland	
Aberdeen Proving Ground	Depleted uranium
Aberdeen Pulsed Reactor Facility	Activation and fission products
Armed Forces Radiobiology Research Institute, Bethesda	Activation and fission products
Army Chemical Center, Chemical and Radiation Lab.	Accelerator

TABLE 4-1 (CONT)

Facility	Type of Contamination
Diamond Ordnance Radiation Facility, Bethesda	Activation and fission products
Edgewood Arsenal, Army Nuclear Effects Laboratory	Accelerator
Naval Medical Center, Bethesda	Accelerator
Naval Ordnance Lab, Silver Springs	Accelerator
Massachusetts	
Army Quartermaster Depot, Natick	2 Accelerators
Michigan	
Detroit Arsenal at Center Line	Accelerator
Nevada	
Nellis Air Force Base	Depleted uranium, plutonium, fission products
Fallon Naval Air Station	Shoal underground nuclear weapon test
New Jersey	
Picatinny Arsenal, Dover	Accelerator
New Mexico	
Kirkland Air Force Base	Unknown
White Sands Missile Range (Trinity Site, Fast Burst Reactor Facility)	Activation and fission products
New York	
Watervliet Arsenal, Watervliet	Accelerator
Ohio	
Wright-Patterson Air Force Base	Activation and fission products, accelerator
Texas	
Fort Worth (Aerospace Systems Test Reactor, Ground Test Reactor)	Activation and fission products
Medina Base, San Antonio	Depleted uranium
Utah	
Hill Air Force Base, Ogden	3 Accelerators
Virginia	
Ft. Belvoir	Activation and fission products
Washington	
Puget Sound Naval Shipyard	Activation and fission products
Sandpoint Naval Station	Ra-226

exploding nuclear weapons using depleted uranium (DU) as a substitute for the fissionable material. Others have been contaminated by firing projectiles containing depleted uranium against hard targets such as armor or tanks, or into soft targets such as sand or dirt. Depleted uranium projectiles have also been fired over the ocean (landing in the sea) and on a firing ranges where they have impacted in areas with other live but undetonated ammunition.

The cost and feasibility of D&D of DOD facilities will vary considerably. Some D&D has taken place at several DU firing ranges with recovered projectile fragments and large quantities of dirt shipped to commercial burial sites. Recovery of projectiles fired at sea or in near coastal areas is problably not feasible. Recovery on ranges contaminated with other undetonated ordnance probably can not take place independently of recovery of the live ammunition which presents a far greater hazard than the DU projectiles. Increasing production, testing, and use of DU projectiles has the potential for generating large quantities of low specific activity waste as well as contamination of large land areas (and perhaps coastal sediments). Quantities of waste which may be generated in the future from this source can not be estimated but would appear to be amenable to some control (i.e., limiting the number of ranges used and not cleaning up each time a firing test is conducted in the same area).

Most of the military nuclear reactors, with the exception of nuclear ship reactors and a few research reactors, have been shut down or dismantled. In general, for those reactors which have been shut down, fuel has been returned to the DOE and some D&D has been performed on the facility. The majority of the facilities have some remaining contamination. Available information is discussed on a case-by-case basis in the following sections.

The U.S. Navy has constructed, or has in process of construction, approximately 150 nuclear submarines and about a dozen nuclear-powered surface ships. Two nuclear-powered submarines have been lost at sea and another five have been decommissioned, defueled, and laid up in Navy shipyards. The Navy is now considering alternative methods to dispose of decommissioned nuclear submarines, since it expects to eventually have to decommission them at a rate of 3 to 4 per year. No indication has been reported on the expected decommissioning rate for nuclear-powered surface ships. In addition to the radioactivity contained in the nuclear-powered submarines and surface ships, low levels of radioactivity are also usually present in harbor sediments in harbors where the ships are serviced. This is true not only for the shipyards listed in Table 4-1, but for other nuclear ship bases such as those at Guam and in Scotland. Radioactivity attributable to nuclear ship operations found in harbor sediments is principally Co-60 at levels which are probably too low to be of consequence and certainly not amenable to ready decontamination.

Very little information has been released by the Department of Energy or the Department of Defense on contamination associated with nuclear weapons accidents in the United States. A few accidents are known to have had contamination associated with the accident but essentially no unclassified information has been reported. Some accidents may also have involved other radioactive (i.e., tritium) but non-fissionable radionuclides. The amount of D&D that might be required at such sites can not be estimated but it is probably small.

The amount of contamination associated with GSA use of military bases as storage sites for strategic minerals is unknown at this time. The quantities of minerals in the stockpile which contain naturally occurring radionuclides is large (millions of tons) while the specific activity may range from 5 to 10 pCi/g for each member of the uranium and thorium chain in bauxite ores to perhaps 100 pCi/g in zirconium ores. Outdoor storage is not uncommon.

Military facilities where accelerators are located are also designated in Table 4-1. The accelerators are listed in Appendix C and the associated D&D is discussed in Chapter 10. These sites will not be discussed in this chapter but are documented here to provide a complete record.

All three military departments have general policies requiring that radioactive wastes be disposed of at commercial radioactive waste burial sites. Some classified radioactive wastes have been shipped to DOE sites. When dumping at sea was an acceptable practice some military wastes were dumped at sea. There may be a very few sites where radioactive wastes have been buried on site but little information is available regarding deliberate on-site burials.

4.2 GENERIC FACILITIES

Most of the military programs which generate radioactive waste can be placed in a few generic categories. The following sections describe the principal categories and the available information on each.

4.2.1 Military Reactors

DOD has had several types of nuclear reactors in operation during the past 30 years. With the exception of nuclear ship reactors most of the DOD reactors have been shut down or dismantled (TIC78).

4.2.1.1 DOD Power Plants for Remote Installations

During the 1950-1960 time frame several small pressurized water nuclear power plants were developed jointly by the DOD and the AEC. These plants were constructed to provide electricity and heat to remote bases and to be available for emergency use in disaster areas. A list of these plants is shown in Table 4-2. All of these plants have been shut down or dismantled. Used fuel was removed and returned to the AEC. Fuel from the Army reactors was sent to Savannah River. Plumbing and other removable materials were shipped to commercial burial sites for disposal. Remaining contamination consists primarily of activation products.* Residual inventories are not readily available. Available information on individual plants is given below.

PM-1 - The PM-1 reactor was operated by the U.S. Air Force at Sundance, Wyoming to provide power for radar units at a Dewline station. The plant power rating was 1000 kW(e) or 9370 kW(t). The facility began operation in 1962 and was shut down in 1968. According to a March 11, 1969 status report on PM-1 dismantling, the radwaste skid package had been

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* Personal Communication, H. Edge, U.S. Army Environmental Hygiene Agency, Edgewood, Md., March 26, 1982.

TABLE 4-2

DOD POWER REACTORS FOR REMOTE LOCATIONS
Source: TIC78

Name	Designation	Location	Startup	Shutdown
Portable Medium Power Plant No. 1 (USAF)	PM-1	Sundance, Wyoming	1962	1968
Portable Medium Power Plant No. 2A (USA)	PM-2A	Camp Century, Greenland	1960	1963
Portable Medium Power Plant No. 3A (USN)	PM-3A	McMurdo Sound, Anarctica	1962	1973
Stationary Medium Power Plant No. 1 (USA)	SM-1	Ft. Belvoir, Virginia	1957	1973
Stationary Medium Power Plant No. 1A (USA)	SM-1A	Ft. Greeley, Alaska	1962	1972
STURGIS Floating Nuclear Power Plant (USA)	MH-1A	Gatun Lake, Canal Zone	1967	1976

decontaminated and was ready for shipment. By four months after the date of the status report, all buildings were to have been razed and land recovered (Fa80).

PM-2A - The PM-2A was an Army reactor operated at Camp Century, Greenland. Its power rating was 1560 kW(e) or 10,000 kW(t). The facility began operation in 1960 and was shut down in 1963. PM-2A was removed in 1964. The entire area was decontaminated to Danish specifications. A well 190 feet deep with a 50 foot diameter hole at the bottom of the well was left per agreement with the Danish government. Small quantities of liquid waste (about 20 millicuries per year) were placed in this hole during reactor operation (DTI62). Nothing else was left at Camp Century.* The reactor vessel was shipped to Idaho National Engineering Laboratory for testing (TIC78).

PM-3A - The PM-3A was a Navy reactor operated to produce electricity and fresh water at McMurdo Sound in the Antarctic by the Naval Nuclear Power Unit. Its power rating was 1500 kW(e) or 9510 kW(t). It began operation in 1962 and was shut down in 1973. After shutdown the reactor was dismantled and shipped to the United States.

At some time during operation the gravel around the reactor was contaminated. When the site was decontaminated, it was required by international treaty that all radioactive contamination be removed from the Antarctic. Starting in 1976, about 13,400 tons of contaminated rock, wood, and metal debris were shipped to a garbage dump and burn area at the Naval

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* Personal communication, W. Krieger, U.S. Army Corps of Engineers, Ft. Belvoir, March 26, 1982.

Construction Battalion Center at Port Hueneme, California. The material is in storage there and is surrounded by an earthen berm. The pile is about 60 feet wide, 270 feet long and 15 feet high and rests on asphalt coated basins. Radionuclides present include naturally occurring uranium and thorium chain radioisotopes, as well as several activation and fission product radioisotopes. Average concentrations of some of the reactor-produced nuclides in contaminated crushed rock were 70 pCi/g Cs-137, 2.4 pCi/g Sr-90, 3 pCi/g Co-60, and 1 pCi/g Eu-152 (An78). The material is now being used as fill for selected on-base construction projects such as roadbeds.

SM-1 - The SM-1 was an Army reactor operated at Ft. Belvoir, Virginia from 1957 to 1973. Power rating was 1855 kW(e) or 10,000 kW(t). The reactor was used primarily for training but its electrical output was fed into the Ft. Belvoir distribution system in parallel with the Virginia Electric Power Company feed. When the reactor was shut down the used fuel was sent to Savannah River. Decontamination was performed on the facility and all plumbing and other removable material was shipped to a commercial site for burial. The remaining radioactivity in the reactor area has been sealed off. The reactor building is now being used as a museum and school. No inventory information is readily available.*

SM-1A - The SM-1A was an Army reactor operated at Fort Greeley, Alaska from 1962 to 1972. The power rating of the reactor was 1650 kW(e) or 20,200 kW(t). It provided electricity and steam for space heating. After shutdown the reactor fuel was shipped to the AEC at the Savannah River Plant and removable plumbing and other material was shipped to a commercial burial site. The remaining contaminated material, the reactor vessel, has been entombed by filling with concrete. No inventory information is readily available.

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* Personal Communication, W. Kreiger, U.S. Army Corps of Engineers, Ft. Belvoir, Virginia, March 26, 1982.

MH-1A - The MH-1A reactor was installed in the Sturgis (formerly the Liberty Ship Charles H. Cugle) at Mobile, Alabama. The Sturgis was moved to Ft. Belvoir for acceptance testing in 1967 and was moved to Gatun Lake, Panama Canal Zone in 1968 where it began producing power on October 5, 1968 (TIC78). The reactor on the Sturgis was shut down in 1976. The fuel was removed and shipped to the Savannah River Plant. Plumbing and other removable material was removed, packaged and shipped to a commercial burial site. Areas containing residual radioactivity on the ship were welded shut and it was placed in long-term storage in the James River Yards in Virginia. No inventory information is readily available.

4.2.1.2 Test and Research Reactors

The Department of Defense has operated several small test and research reactors for simulating effects of nuclear weapons and for other physical and medical research. A list of these reactors is given in Table 4-3. Most of these small reactors have been shut down or dismantled. Status of the retired facilities is not known. Available information on these reactors is given in the following sections:

The Aerospace Systems Test Reactor was a 10MW(t) pool type reactor used for radiation effects, shielding and materials testing studies. Current facility condition is unknown (TIC78,Nu62).

TABLE 4-3

DOD TEST AND RESEARCH REACTORS

Sources: TIC78, Er79, Nu62, NRC81d

Name	Location	Startup	Shutdown
Aerospace Systems Test Reactor (USAF)	Fort Worth, Texas	1954	1974
Ground Test Reactor (USAF)	Fort Worth, Texas	1953	1973
Nuclear Engineering Test Reactor (USAF)	Dayton, Ohio	1965	1970
Aberdeen Pulsed Reactor Facility (USA)	Aberdeen, Maryland	1968	
Armed Forces Radiobiology Research Institute (DOD)	Bethesda , Maryland	1962	
Fast Burst Reactor Facility (USA)	White Sands, New Mexico	1964	
Army Materials Research Reactor (USA)	Watertown, Massachusetts	1960	1970
Diamond Ordnance Radiation Facility (USA)	Forest Glen, Maryland	1961	1977
Naval Research Reactor (USN)	Washington, D.C.	1956	1970
Walter Reed Research Reactor (USA)	Washington, D.C.	1962	1970
Radiation Effects Reactor (USAF)	Dawsonville, Georgia	1958	1971
Pool Type Reactor (USAF)	Dawsonville, Georgia		1960
Reactivity Test Assembly (USAF)	Ft. Worth, Texas		1974
U.S. Naval Postgraduate School (USN)	Monterey, California		1972
U.S. Naval Hospital (USN)	Bethesda, Maryland		1965

The Ground Test Reactor was a 10MW(t) pool type reactor used for radiation effects, shielding and cryogenic studies. Current facility condition is unknown (TIC78,Nu62).

The Nuclear Engineering Test Reactor was a 10MW(t) tank type reactor used for materials testing, reactor component testing, training, and other research studies. Current facility status is unknown (TIC78,Nu62).

The Aberdeen Pulsed Reactor Facility is located at the U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Md. It is a bare, fast, prompt burst 10kW(t) reactor. (TIC78).

The Armed Forces Radiobiology Research Institute (AFFRI) reactor is operated by the Defense Nuclear Agency of the DOD. It is a 100kW(t) uranium-zirconium hydride reactor which began operating in 1962 and is still in use. The reactor is capable of being pulsed and of steady-state operation (TIC78).

The Fast Burst Reactor Facility is a 10kW(t) bare, fast, prompt burst reactor.

The Army Materials Research Reactor was a pool type 5MW(t) reactor. It was used for radiation effects studies. The fuel has been removed but the reactor is considered to be in a standby mode (TIC78).*

The Diamond Ordnance Radiation Facility was a TRIGA-Mk F reactor. Its power rating was 250kW(t). The fuel was returned to DOE. The pool area was decontaminated and is now being used for radioactive waste storage. The pool will eventually be filled with concrete. The control panel was shipped to AFRRI (TIC78).*

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* Personal communication, H. Edge, U.S. Army Environmental Hygiene, Edgewood, Md., March 1982

The Naval Research Reactor was a 1MW(t) pool type reactor located at the Naval Research Laboratory. Current facility status is unknown.

The Walter Reed Research Reactor was a 50 kW(t) homogeneous solution type reactor located at the Walter Reed Army Institute of Research. It began operation in 1962 and was shut down in 1970. Its license was terminated in 1972. Some contamination still remains at the site (TIC78).*

The Radiation Effects Reactor was a 3 MW(t) pool type reactor. The reactor title was transferred in 1962 from the Air Force to the GSA. In 1965 the title was transferred from GSA to Lockheed (the original operator for the Air Force). Lockheed's license was terminated in 1971 (TIC78, Er79).

Pool Type Reactor (USAF) - This was a 10 w(t) pool type reactor operated by Lockheed Corporation in 1960 (only). Its license was terminated in 1960 (TIC78, Er79).

Reactivity Test Assembly - This was a 1 MW(t) test assembly. It has been dismantled and was decommissioned in 1974 (NRC81d).

U.S. Naval Postgraduate School - A research reactor with a power rating of 0.1 w(t) was operated at the U.S. Naval Postgraduate School. Its license was terminated in 1972 (Er79).

U.S. Naval Hospital - A research reactor with a power rating of 5 w(t) was operated at the U.S. Naval Hospital in Bethesda, MD. The reactor has been dismantled and its license was terminated in 1965 (Er79).

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* Personal communication, H. Edge, U.S. Army Environmental Hygiene Agency, Edgewood, Md., March 1982.

4.2.1.3 Naval Propulsion Reactors

Through 1978 the U.S. Navy had 113 nuclear powered submarines and 11 nuclear-powered surface ships in operation (Mi79). Another 29 submarines and 2 surface ships were under construction (TIC78). Eight submarines had been shut down, dismantled or lost at sea. This figure includes the USS Seawolf, which was shut down, its sodium-cooled reactor removed, and a pressurized water reactor installed. The Seawolf was then recommissioned. A list of nuclear-powered submarines and surface ships is given in TIC78.

Two nuclear submarines have been lost at sea in the Atlantic Ocean. The Thresher sank April 10, 1963, in water 8,500 feet deep. The Scorpion went down in May 1968 in more than 10,000 feet of water.

The reactor vessel and reactor plant components removed from the sodium-cooled Seawolf reactor plant, which contained about 33,000 curies, were welded into a steel barge. They were scuttled in 9,000 feet of water on April 8, 1959 in the Atlantic Ocean at latitude 38° 30'N and longitude 72° 06'W. As of 1980, this radioactivity had decayed to less than 5,000 curies, essentially all Co-60 (Mi71). The Navy has been unable in recent years to find the Seawolf reactor to monitor it (Ca80).

Until June 1968, the Navy was disposing of low-level solid radioactive wastes from Hawaii in 15,000 feet of water at a location in the Pacific Ocean 55 miles from Hawaii. Wastes were packaged in 55-gallon steel drums weighted with concrete. This practice was discontinued in June 1968 and since that time all Naval solid radioactive wastes have been shipped to commercial waste burial sites (Mi71). (A later report by the same authors gives the cutoff date as 1970.)

Five nuclear submarines have been decommissioned, defueled, and laid up in Navy shipyards. At least two of these five vessels are in protective storage in the Puget Sound Naval Shipyard (Ca80). The fuel, like expended fuel, is shipped from the refueling shipyard by DOE to the DOE facilities in Idaho for processing. In 1979, the Navy prepared an enviromental impact assessment for a Puget Sound dockside facility to accomplish disassembly, inspection, reassembly and interim handling of reactor components during servicing of nuclear powered aircraft carriers. The facility is also to be used in support of reactor servicing operations on nuclear cruisers and submarines. The facility was required because the Navy did not have facilities suitable for supporting refueling operations on nuclear powered carriers on the west coast.

To support its nuclear powered ships, the Navy has extensive facilities which include 9 shipyards, 13 tenders, and 2 submarine bases. In order to assess the environmental impact of the nuclear powered ships, the Navy conducts an extensive environmental monitoring program at these sites. Total solid radioactive waste generated by Navy nuclear ships and support facilities during 1978 was less than 1359 cubic meters which contained less than 72 curies. More detailed information is given in Mi79.

The Navy is planning to prepare an EIS to explore the alternative methods of disposing of decommissioned nuclear submarines. As the Federal Register Notice on this (DOD82) states, the Navy is faced with the prospect of eventual decommissioning perhaps over 100 nuclear submarines at a rate of 3 to 4 per year. Experience to date may have some relevance in selecting options. In the case of the two U.S. nuclear submarines lost at sea, the Navy has made periodic environmental surveys at the sites. To date the only radioactivity detected has been found in bottom sediments as low levels of Co-60.

There are no plans to decommission nuclear powered surface ships.

4.2.2 Depleted Uranium Munitions

The military services have been interested in the use of depleted uranium (DU) in manufacture of projectiles for approximately 30 years. Its relatively low cost, high density, pyrophoric properties on impact, and ready availability have made it a very attractive material for armor piercing projectiles (E181). Depleted uranium was used in the early 1950's in experimental projectile components in firing programs conducted at Aberdeen Proving Ground (ABG), Maryland. Projectile impact points were in the Chesapeake Bay on firing ranges controlled by APG. Quantities of uranium used were probably small.* Beginning about 1973, the Air Force began to produce DU penetrators for use in a tank-killing projectile. Millions of these rounds are now in Air Force inventory alone and are being produced at the rate of about 7 million rounds per year (E181).

Air Force DU ammunition has been used at Nellis Air Force Base in Nevada (E181) and at Eglin Air Force Base, Florida. A LASL report (Wh80) presents a very small amount of data on DU in soil in Test Area C-74L at Eglin. Another LASL report (Ha74) describes the composition of some of the munitions used by the different military services. The report also reviews ecological considerations and anticipated consequences associated with use of the projectiles. According to Ha74 each 30-mm GAU-8/A projectile contains about 300 grams or 100 microcuries of DU.

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* Personal communication, D. Hendricks, Don Hendricks and Associates, Inc., March 25, 1982.

The Navy in 1975 was performing operational testing on the Phalanx gun system which uses M61A1 aircraft cannon, capable of firing 6000 rounds of 20-mm ammunition per minute. The Mk 68 Mod 0 ammunition used in the Phalanx contains a DU penetrator. One Phalanx system in 1975 was undergoing operational tests on board ship while other tests were initiated at Camp Roberts, California. In these tests penetrators were fired against several targets built to the diameter and hardness expected of the missiles which would be the targets for this weapon system (Ta75).

The Army and Marine Corps also have in inventory DU penetrators contained in projectiles as large 105 mm. The M774 and M735E1 projectiles contain DU. Army testing of DU projectiles has taken place at Aberdeen Proving Ground and White Sands Missile Range.

The Army is also providing some ammunition storage for other DOD departments. Army ammunition depots are currently licensed to possess more than 25 million kg of DU munitions. The actual amount in storage, however is less than the possession limit. The two main depots for DU storage are the Seneca, N.Y. and Sierra, Ca. Army Depots. The actual amount of DU currently being consumed in testing and training activities in the different services is not readily available. To minimize environmental contamination, current Army testing of DU munitions is either conducted by firing the projectiles into contained environments to minimize the spread of DU fragments or by firing the projectiles to minimize pyrophoricity and to allow fragment recovery. In firing tests at White Sands Missile Range fragment recoveries of perhaps 90 percent have been reported. The Army is not routinely using DU projectiles for training exercises.* It is not known if the other departments are observing the same practice. Use of DU munitions has the potential for creating widespread low specific acitivity contamination at a number of sites.

4.2.3 White Sands Missile Range (WSMR)

Limited testing of DU projectiles against soft targets has taken place at the Army's WSMR. As noted in the preceding section, fragment recoveries were reported to be as high as perhaps 90 percent.* WSMR has one of the Army's two operating reactors, the Fast Burst Reactor Facility (FBRF). The FBRF is a 10 kW(t) bare, fast, prompt burst reactor which began operation in 1964 (TIC78). The WSMR is also licensed to possess a wide range of byproduct materials as well as uranium and thorium.

The largest amount of contamination at WSMR, however, is the large land area contaminated by the Trinity nuclear bomb test. Trinity was the world's first nuclear weapon test with a yield of about 19 kilotons (La 68). The Trinity weapon was an all-plutonium device which contained considerably more plutonium than the modern weapons. A number of studies have been performed to evaluate the extent of the spread of plutonium from the Trinity test. One 1978 study (Do78) indicates that if background plutonium in soil levels are of the order of 1 nCi/m^2 (nanocuries per square meter), then levels within the WSMR can be as much as 1100 nCi/m^2 while levels off site at distances of 30 to 40 miles can be as much as 86 nCi/m^2. Trinity was detonated on July 16, 1945.

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* Personal communication, T. Grucci, Safety Office, U.S. Army Material and Development Readiness Command, March 25, 1982.

4.2.4 Fallon Naval Air Station

On October 26, 1963, the AEC detonated a 12-kiloton nuclear weapon underground at a site on the Fallon Naval Air Station east of Fallon, Nevada. The test was contained with no releases of radioactivity. After several years of post-detonation environmental monitoring, custody of the test site was returned to the Navy by AEC. No surface or near surface contamination is present at the site. Subsurface contamination exists near the detonation point in the form of activation and mixed fission product weapons debris.

4.2.5 Iowa Army Ammunition Plant

The Iowa Army Ammunition Plant near Burlington, Iowa was used for a number of years until 1975 by the AEC (later ERDA) as a nuclear weapons assembly facility. No contamination due to weapons assembly operations has been reported at the plant. However, about 4000 kg of depleted uranium were dispersed to the environment during tests conducted at Firing Site 12. Extensive decontamination was performed in 1974 following detailed soil surveys. A total of 31,746 cubic feet of contaminated soil was shipped to the commercial waste burial site at Sheffield, Illinois. The area north of the firing point was plowed after decontamination. Soil samples taken following decontamination indicate that soil concentrations at 15 feet from ground zero range from 16.6 to 473 micrograms U per gram of soil, levels at 30 feet range from 5.5 to 767 micrograms U per gram soil, and at 65 feet levels range from 26.7 to 50.0 micrograms U per gram of soil (Ja77).

4.2.6 GSA Stockpile Sites on Military Reservations

Under the Strategic and Critical Materials Stockpiling Act the President has assigned stockpiling activities to the Director, FEMA while the actual stockpile management functions were delegated by Executive Order 12155 to the Administrator, GSA. Many of the stockpiled minerals contain natural radioactivity in concentrations up to 50 pCi/g.

The individual stockpiles vary from thousands to millions of metric tons. In 1977 GSA was using 34 military depots (GSA78).

Locations of these sites are not given in the reports although it is known that radioactive zircon or titanium sands are stored on an open outdoor pad at a GSA depot on the site of the former Jeffersonville Quartermaster Depot in Jeffersonville, Indiana.* The Granite City Army Depot, Granite City, Illinois, has also been reported as a stockpile site where radioactive minerals were removed and the site decontaminated.** A November 28, 1979 article in the Louisville Courier-Journal newspaper (Louisville, Kentucky) reported that thorium had been buried in the chemical agent burial ground at the Crane Naval Weapons Support Center near Crane, Indiana, and had been removed. The article did not say where the thorium was taken or if the site was decontaminated. It is not known whether the thorium was associated with stockpile or munitions functions.

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* Personal communication, D. Hendricks, Don Hendricks and Associates, Inc., March 25, 1982.

** Personal communication, T. Grucci, op. cit.

4.2.7 Nellis Air Force Base and Nellis Bombing and Gunnery Range

Nellis Air Force Base, located 8 miles northeast of Las Vegas, Nevada, encompasses about three million acres including extensive bombing and gunnery ranges. The Nellis Bombing and Gunnery Range borders the DOE Nevada Test Site on 3 sides. Portions of the range have been contaminated with radioactive fallout from atmospheric nuclear weapons and weapons safety tests conducted during past years. Although most of the fission and activation products have decayed to levels where external gamma radiation is not a serious problem, some parts such as the Frenchman Flat and Tonapah Test Range areas are extensively contaminated with plutonium and may some day require substantial D&D efforts.

Test firing of depleted uranium projectiles against tanks has also been performed on the Nellis Bombing and Gunnery Range (See Section 4.2.2).

4.2.8 Nuclear Weapons Accidents (Broken Arrows)

A number of accidents involving nuclear weapons have occurred during the past 30 years. While none of these accidents have resulted in a nuclear explosive yield, scattering of the radioactive plutonium or uranium in the weapon has occurred on several occasions. Nuclear weapons accidents are frequently referred to by the military code name of "Broken Arrow".

A partial list of nuclear weapons accidents in the U.S. has been compiled from the popular literature, since very little information exists in the technical literature. Estimates of the total number of weapons accidents range up to more than 50 (Ha81a, Lo69). Table 4-4 is a summary of the available information. Data is not readily available to indicate whether contamination still exists at accident sites where radioactive material was scattered. One exception is the Medina Base where contamination is still believed to be present.*

4.2.9 Sites Contaminated with Simulated Fallout

Tests were carried out at military bases to study the effectiveness of various methods for decontaminating surfaces. In these tests short half-life radionuclides were sprayed or otherwise dispersed on land, buildings, vehicles, crops and roads. Different removal methods such as washdown, brushing, scraping, or plowing were then evaluated. Since the radionuclides used were short half life no residual contamination is expected at these sites. However, at Camp Parks, Ca, D&D is underway on a hot cell contaminated with strontium-90. Multi-curie quantities of strontium-90 were used as a generator for the short half-life daughter. The camp is presently being used for reserve training. Cold weather tests of a similar nature were carried out at Camp McCoy, Wi., although nothing has been found to indicate residual contamination at that site.

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* Personal communication, D. Hendricks, Don Hendricks and Associates, Inc., March 25, 1982.

TABLE 4-4

NUCLEAR WEAPONS ACCIDENTS

Date	Location	Weapon System
2/13/50	Pacific Ocean, off Puget Sound, WA	B-36
4/11/50	Manzano Base, NM	B-29
7/13/50	Lebanon, OH	B-50
8/05/50	Travis AFB, SW of Sacramento, CA	B-29
1/9/56	Kirtland AFB, S of Albuquerque, NM	B-36
5/22/57	Kirtland AFB, S of Albuquerque, NM	B-36
10/11/57	Homestead AFB, FL	B-47
12/12/57	Fairchild AFB, Spokane, WA	B-52
2/05/58	Savannah, GA, 5 miles off coast	B-47
3/11/58	Florence, SC	B-47
5/22/58	Leonardo, NJ	Nike Missile
11/04/58	Dyess AFB, Abilene, TX	B-47
11/26/58	Chennault AFB, Lake Charles, LA	B-47
7/06/59	Barksdale AFB, Shreveport, LA	C-124
10/15/59	Glen Bean, KY	B-52 & KC-135
6/07/60	McGuire AFB, Wrightstown, NJ	BOMARC Missile
1/19/61	Monticello, UT	B-52
1/24/61	Goldsboro, NC	B-52
3/14/61	Yuba City, CA	B-52
11/13/63	San Antonio, TX (Medina Base)	Storage Site
1/13/64	Cumberland, MD	B-52
12/05/64	Ellsworth AFB, SD	LGM 30B (Minuteman)
12/08/64	Grissom AFB, Evansville, IN	B-58
8/09/65	Searcy, AR	Titan Missile
10/12/65	Wright-Patterson AFB, Fairborn, OH	C-124
8/24/78	Rock, KS	Titan Missile
4/ /80	Wichita, KS	Titan Missile
9/16/80	Grand Forks AFB, ND	B-52
9/19/80	Damascus, AK	Titan II ICBM

4.3 EXISTING CONTAMINATION

Most of the non-operating DOD portable power plants and test reactors have some residual contamination, primarily as activation products. The operating test reactors still contain nuclear fuel as well as fresh fission products. Waste volumes and inventories are not available. A similar situation exists with the naval propulsion reactors although reactor inventories would be expected to be larger because of larger reactor power ratings.

Sites where DU munitions have been and are being used will have residual DU contamination in quantities varying from site to site and from day to day depending on whether the site is in active use for DU munitions and whether D&D has been, or is being, performed.

Plutonium and fission product contamination at the White Sands Missile Range from the Trinity Test has undergone little change since the detonation except from natural weathering forces. Although some consideration by DOE has been given to possible D&D in the off-site Chupadera Mesa area where elevated levels of plutonium have been found (see Section 3.3.2), there are no reported plans at this time to carry out D&D in this area.

There is no surface contamination at the Project Shoal nuclear weapons test site on the Fallon Naval Air Station. It would not be economically feasible to attempt subsurface removal of the underground nuclear weapons debris.

Some surface and near-surface DU contamination exists at the Iowa Army

Ammunition Plant and the Medina Base. There are no reported plans to perform further decontamination at these sites. There are also no known reports of plans to further decontaminate areas contaminated by nuclear weapons testing on the Nellis Air Force Bombing and Gunnery Range, although some D&D of DU firing areas may take place.

The extent of contamination at GSA strategic material stockpile sites is unknown. Any contamination would be in the form of naturally occurring radionuclides. The extent of contamination at nuclear weapons accident sites is also unknown. Possible contaminants would be plutonium, enriched uranium, and tritium.

On-site burials have been reported at the Crane Naval Weapons Support Center (see Section 4.2.6) and at the Sandpoint Naval Station near Seattle, Wash. In 1976 radium-226 contamination was found on site at the Sandpoint Naval Station in an area reported to have been used as a radioactive waste burial site. Although no report is available, it is believed that the Navy subsequently performed decontamination in this area.

4.4 D&D PROGRAMS

Military D&D programs are usually oriented toward the needs of the individual military department since these needs may be unique. The Navy, for instance, has an ongoing D&D program for its nuclear ships. Under this program the Navy has shut down or dismantled five nuclear submarines. A third submarine (the USS Seawolf) had its original sodium-cooled reactor replaced and was recommissioned with a pressurized water reactor. The Navy has also issued a Federal Register announcement of intent to prepare a draft environmental impact statement to assess alternatives that could be used to permanently dispose of decommissioned, defueled submarine reactor plants (DOD82). This draft EIS should formally document the nuclear submarine D&D program.

Most of the military D&D programs have used the SAFSTOR alternative. Many facilities have had some decontamination but will require further work before the facilities can be released for unrestricted use. The Army has an ongoing environmental surveillance and monitoring program for its shutdown reactors. Disposal of decommissioned, defueled nuclear submarines at sea would probably fall in the ENTOMB category while storage in shipyards would fall in the SAFSTOR category.

The Coast Guard and Marine Corps would be expected to generate very little, if any, radioactive waste since they are relatively small organizations and do little research and development using radioactive materials compared to the Army, Navy and Air Force.

The Army, Navy and Air Force have also shut down or dismantled small research reactors, while the Army has additionally shut down or dismantled six portable power reactors.

No known programs are presently underway to decomtaminate large contaminated land areas such as the Nellis Bombing and Gunnery Range or the White Sands Missile Range.

4.5 CHARACTERIZATION OF WASTES

Military program changes in recent years have changed the types and quantities of military wastes being generated. Only two Army research reactors are still operating. With the exception of the Navy nuclear ship program, most of the other military reactors have also been shut down or dismantled. Similarly, some of the military accelerators have also been shut down or transferred to other agencies. Most of the D&D was performed on these facilities several years ago.

Wastes currently being generated within the Army consist primarily of hospital and laboratory wastes including scintillation vials, some DU scrap in dirt from projectile test firing decontamination, and items containing radioactivity; such as, radium and tritium dial compasses, watches, gun sights, and instrument faces. Over the past four years, Army generated radioactive waste which is shipped to commercial sites for burial has averaged about 400 to 450 cubic meters per year, with current burial costs running about $14 per cubic foot. Most of the Army waste is extremely low specific activity.* Except for nuclear ship wastes, Navy and Air Force wastes would be expected to be similar to Army wastes. Navy nuclear ship wastes in 1978 were less than 1400 cubic meter.

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* Personal communication, R. Biela, Rock Island Arsenal, March 25, 1982.

5. DEPARTMENT OF COMMERCE CONTROLLED FACILITIES

5.1 INTRODUCTION

The Department of Commerce (DOC), through the U.S. Maritime Administration, controls the Nuclear Ship Savannah. It also controls, through the National Bureau of Standards (NBS), the Center for Radiation Research at the Bureau. The NBS facilities include a reactor and several accelerators. This chapter summarizes available information on the N.S. Savannah and facilities at the NBS.

5.2 FACILITY CLASSES

The facilities include two reactors and several accelerators, which are evaluated in Chapter 10.

5.3 DOC PROGRAMS FOR D&D

The DOC does not appear to have official D&D programs, but it did decommission the N.S. Savannah.

5.3.1 DOC Facilities

The DOC facilities include the N.S. Savannah, its support facilities, and the NBS research reactor.

5.3.1.1 Status

The N.S. Savannah and the associated facilities have all been deactivated. The NBS reactor has operated for almost 20 years. It is projected to operate for another 10 to 20 years, depending on program requirements.

5.3.1.2 Representative Facilities

Representative facilities are not used except to estimate D&D wastes from the NBS reactor.

5.3.1.3 Existing Contamination

The N.S. Savannah, a combination passenger and cargo vessel, was built as a joint project by the Maritime Administration and the Atomic Energy Commission to demonstrate the safety and reliability of using nuclear propulsion for commercial purposes. The Savannah's pressurized water reactor was rated at 80,000 kW(t) with a 22,000 shaft horsepower nuclear steam generating system. The Savannah was designed as a demonstration ship with a power plant that was relatively small for commercial operation. As a result the Savannah did not prove to be economically competitive. (TIC78, TNI74).

For refueling, servicing and handling of radioactive waste from the Savannah, a shore facility was constructed at Todd Shipyard, Galveston, Texas. A nuclear servicing vessel, the N.S.V. Atomic Servant, was also built. The Atomic Servant was not self-propelled and had the principal function of handling, processing and packaging radioactive waste (Re61).

The Savannah was expected to generate 35 cubic feet of contaminated resins each 100 days with an additional 1 to 10 barrels of other wastes also generated each 100 days.

The fuel was UO_2 with an initial U-235 loading of 310 kg and a U-238 loading of 6,800 kg for an initial average enrichment of about 4.5 weight percent. The Savannah began operation in December 1961 and was shut down in 1971. The reactor core was removed in 1971 and shipped to Savannah River (TNI71). About 1977 the ship was towed to Charleston, South Carolina. It is currently tied up at Patriot's Point at Charleston. The Partriot's Point Development Authority is proposing to convert it into a hotel and tourist attraction.

The Nuclear Regulatory Commission (which licenses the ship) and a Maritime Administration contractor are presently doing closeout surveys on the Savannah preparatory to transferring the ship to the Patriot's Point Development Authority. If transfer takes place the ship will remain indefinitely at the Patriot's Point location.*

The on-shore facility at Todd Shipyard has been decontaminated, with no contaminated areas or wastes attributable to the N.S. Savannah remaining at the shipyard. The N.S.V. Atomic Servant was decontaminated and decommissioned about 1979.**

The NBS reactor is located in Gathersburg, Md. and went on line in 1963. It is in the process of having its power rating increased from 10 Mw(t) to 20 Mw(t). It is anticipated that this reactor will remain in use for at least another 10 to 20 years, depending on program requirements.

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* Personal communication, C. Hosey, U.S. Nuclear Regulatory Commission, Region II, Atlanta, March 26, 1982.

** Personal communication, C. Winters, Todd Shipyard, Galveston, Texas, March 26, 1982.

5.3.1.4 D&D Procedures

No further D&D connected with the N.S. Savannah should be necessary, unless a problem is found during the ongoing closeout survey.

D&D will be necessary at some indeterminate future time at the NBS reactor facility. DECON appears to be the preferred D&D alternative (Ko82). The reactor could be put in SAFSTOR for some period prior to DECON.

5.3.1.5 Characterization Of The Wastes

Following core removal from the N.S. Savannah in 1971, the ion exchange resins, the main coolant pumps, and all contaminated water were removed, packaged and shipped to the commercial waste burial site at Barnwell, SC for disposal. Other components, such as the control rods, remain in the pressure vessel on the ship. Periodic surveys of the ship were made by Todd Shipyard personnel while the ship was docked in Savannah until 1977. Since then another Maritime Administration contractor has continued these surveys.

At this time there are about 42,000 curies of activation products and mixed fission products contained on board the Savannah in its reactor components.* Almost all of this activity is in the form of Fe-55 and Co-60. However, Nb-94 and other long half-life activation products are also present.

Wastes from D&D of the NBS reactor are estimated from the reference test reactor (see Appendix A, based on Ko82). The NBS reactor has a lower power than the reference test reactor (20 versus 60 Mw) and probably has been used more like a research reactor. Therefore, the wastes of the test reactor are scaled down by a factor of 10, resulting in estimates of 500 m^3 of materials with a total of 41,000 Ci of activity (mostly activation products).

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* Personal communication, C. Hosey, op. cit.

6. DEPARTMENT OF INTERIOR

6.1 INTRODUCTION

The Bureau of Land Management (BLM), through the Department of Interior (DOI) is responsible for managing public land and issuing mineral leases. In most instances the DOI loses jurisdiction for a piece of land by transferring the patent to the claimant or transferring responsibility to the pertinent Federal Agency (e.g., DOE in many cases for uranium mill tailings). However, in some cases where mill sites have been located on public lands without proper reporting or where records are not sufficient to designate a responsible party, the DOI retains responsibility (DOE79a).

Three inactive mill sites have been identified on DOI land (DOE79a). These sites are not included in the DOE remedial action programs (DOE82a and DOE80f). There may also be active and inactive uranium mines on DOI land. These possible sites are not discussed here. They are included in a separate report (Be82a).

In addition to the inactive mill tailings the DOI, through the U.S. Geological Survey (USGS), operates a Triga Reactor at its facilities in the Federal Center in Denver, Colorado (TIC78) and there is contamination at the Bureau of Mines (B of M) Facility in Albany, Oregon (Ja79). The Bureau of Mines is an agency in DOI. The Albany site is a FUSRAP site (see Chapter 3).

Because of the involvement of the B of M in the Manhattan Project and ore processing research, there is radioactive contamination at several

B of M facilities. However, these have been identified in the early phase of FUSRAP. The contamination has generally been found to be minimal.

6.2 FACILITY CLASSES

Three of the Interior facilities are inactive uranium mill tailings piles. Apparently there are no structures involved (DOE79a). The other facility is a Triga Reactor.

6.3 PROGRAMS FOR DECOMMISSIONING AND DECONTAMINATION

There are no identified programs for D&D. However, a private company does propose to remove the tailings from one of the sites for reprocessing.

6.3.1 DOI Facilities

Three uranium mill tailings piles and the reactor are grouped together.

6.3.1.1 Status of Facilities

The three mill tailings sites are all inactive sites. Their former operating lifetime is not known.

The operating lifetime for the reactor is potentially about 40 years, the same as the reference research reactor (Appendix A).

6.3.1.2 Existing Contamination

The following items describe the available information on the sites.

- The AEC Mill Tailings Pile - This site is titled by DOE79a as the "AEC" site. Apparently this does not designate ownership. The site is located in Wayne County, Utah, southeast of Torrey in the Richland BLM District. There is some confusion on the actual coordinates (DOE79a p. C-51). There appear to be about 500 m^3 of material on site. A BLM employee reported he did not obtain elevated readings with a scintillometer survey meter (calibration and range unknown). It is speculated that this pile consists of tailings from 0.1% U_3O_8 or less ore.

- The Shitamaring Canyon Mill - This abandoned mill is located in Garfield County, south of Hanksville, Utah near Lake Powell. Mr. C. Horsburgh of the Richfield BLM district office indicated that Plateau Resources bought out Hydrojet's properties in the 1970s. Apparently the latter company operated the mill. Plateau has to get a new mill license, but plans to move the material to a new site and rework it prior to October 1982. They have reserved $750,000 for hauling the material from the two mill ponds. There are no estimates of volumes available. Apparently there is a considerable amount of uranium in the tailings; indicating ore was fairly high grade.

- South Cottonwood Wash - This site is about 22 km southwest of Blanding, Utah, in San Juan County. The site operated in the early 1940s and very little is known of the operation. It is even rumored the tailings may have been moved to the Monticello Mill for reprocessing (DOE79a).

- USGS Triga Reactor - This reactor is located at USGS facilities in Denver, Colorado. The reactor started up in 1959, and we find no record of its shutdown. This reactor is very similar to the reference research reactor in Appendix A. The estimated D&D waste is 35m^3 and 1,400 Ci of activation products.

6.3.1.3 D&D Procedures

The D&D procedures for the mill tailings sites should consist of removing the tailings to a suitable off-site location (DECON) or stabilizing the material in place. The latter alternative would be SAFSTOR or ENTOMB depending on the extent of stabilization and the features of the site. Given the small amounts of materials, DECON would appear to be preferred to minimize the number of sites needing surveillance.

The preferred D&D procedure for the research reactor is DECON, however SAFSTOR could also be used (Ko82). In either case the reactor would be defueled and the fuel and contaminated material removed from the site. The choice is whether the reactor vessel is removed shortly after shutdown or whether it is sealed in place to allow for decay of some of the activity.

6.3.1.4 Characterization of Wastes from D&D

The wastes from the mill tailings sites are uranium mill tailings and possibly ore. The concentrations of radioactivity probably range from 100 to 1000 pCi/g or more of Th-230, Ra-226, and the associated progeny. There are indications that there may be considerable residual uranium at the Shitamaring site.

Most of the activity associated with the research reactor is activation products. See Appendix A for details. It is estimated the total volume of D&D waste will be less than 100 m^3, with an activity of about 1,400 Ci (mostly from the reactor, at time of shutdown).

6.3.1.5 Residual Materials

The wastes from the tailings piles are not expected to contain recyclable materials. A company is planning to reprocess the tailings at the Shitamaring site, but the same volume of tailings and acti vity of Th-230 and Ra-226 will remain.

If the research reactor is used for its full life it probably will not contain much recyclable material. If shut down early in its life it may be sold or given to another user.

7. GOVERNMENT SERVICES ADMINISTRATION

7.1 INTRODUCTION

Prior to 1979 the Government Services Administration (GSA) was responsible for managing the National Stockpile Storage Sites of strategic materials. With the formation of the Federal Emergency Management Agency (FEMA) in 1979 responsibility for the stockpiles was given to FEMA, but, GSA still retains responsibility for management of the stockpiles (Executive Order 12155, GSA78). The stockpiles include ores of thorium, chromium, copper, cobalt, magnesium, zirconium, and other minerals. These ores are often associated with elevated concentrations of thorium and uranium.

7.2 FACILITY CLASSES

All of the subject facilities are stockpiles of ores which may contain elevated concentrations of thorium and uranium.

7.3 GSA PROGRAMS FOR D&D

GSA does not have programs for D&D for contaminated facilities, but has programs for disposing of surplus facilities (GSA77 and GSA78).

7.3.1 Stragetic Ore Stockpiles

The Government Services Administration supervises strategic material stockpiles at over 100 sites. How many sites contain ores with elevated concentrations of radioactivity is not known. The ores are often stored in open piles similar to mine waste or tailings.

According to the semiannual FEMA Stockpile Report to the Congress for the period April through September 1980 the following materials were included in the national stockpile inventory:

Material	Quantity (MT)
Thorium nitrate	3,000
Bauxite - Jamaica type	9,000,000
Bauxite - Surinam type	5,400,000
Columbium concentrates	800
Rutile	35,000
Tantalum minerals	1,100
Rare earth oxides	460
Chromite ores	2,800,000

GSA78 indicates the storage sites are 28 GSA depots, 34 military depots, 14 other government depots, and 34 plants and other sites. The concentrations of radioactivity (from each member of the uranium or thorium chain) are expected to range from 5 to 10 pCi/g for bauxite ores to 100 pCi/g for zirconium ores. The stockpiles consisted of about 30×10^6 MT in 1977 (GSA77). As shown above, by 1980 that quantity appears to have been reduced to about 17×10^6 MT.

7.3.1.1 Status

The status of the sites is not known. Some of the stockpiles are being reduced (GSA78). There was a moratorium on stockpile disposals or acquisitions during most of 1977. Several sites are listed under DOD activities in Chapter 4.

7.3.1.2 Representative Facility

There is minimal information for characterizing a reference facility. However, it is postulated that a representative site contains about 10^6 MT of ore with a uranium concentration of 50 pCi/g (U-238). Assuming a density of 1.6 g/cm^3 and a pile height of about 6 meters, the storage area would be about 0.1km^2, containing 50 Ci of the parent radionuclide.

7.3.1.3 Existing Contamination

Depending on the storage conditions there could be contamination of the surrounding area from blown dust and water erosion.

7.3.1.4 D&D Procedures

D&D procedures will be similar to those for the UMTRAP given in Chapter 3. Assuming the reserves are used, the surface under the pile would be contaminated and some soil from under the piles would also have to be treated as radioactive waste.

7.3.1.5 Characterization of Wastes

The wastes will be similar to low grade uranium ore (0.02%) or mill tailings. Depending on how the reserves are removed waste volumes could be around 10^4 m^3 (10^5 m^2x0.1 m depth) per site or more. It is postulated that there are the equivalent of 20 sites, similar to the representative site, used for storage of ores with elevated concentrations or uranium or thorium. Toxic heavy metals may also be present. Cleaning the surrounding areas could increase D&D waste volumes by a factor of 2 to 5 or more.

A basic concern is that ore reserves are removed from sites, and not abandoned.

7.3.1.6 Residual Materals

It is possible that much of the contaminated material could be removed and processed with the ore.

8. DEPARTMENT OF HEALTH AND HUMAN SERVICES

The Department of Health and Human Services (DHHS) operates the National Institites of Health (NIH) in Bethesda, Maryland. The research facilities at NIH include several accelerators. The facilities also are assumed to include theraputic radiation sources (e.g., Co-60) and facilities for the diagnostic and theraputic use of radionuclides. However, we have not identified these facilities and they are not considered. Furthermore, other than sealed sources, the radionuclides will be short half-life materials. The accelerators are listed in Appendix C and discussed in Chapter 10.

9. VETERANS ADMINISTRATION

9.1 INTRODUCTION

The Veterans Administration (VA) is an independent Federal Agency. It operates at least two identified facilities that may require D&D. A Triga reactor is located at the Omaha, Nebraska VA Hospital (TIC78). An accelerator is located at the VA Hospital in Minneapolis, Minnesota. In addition to these facilities, the VA may possess other accelerators and radiation therapy sources (Co-60) for cancer treatment and research. However, the other facilities are probably of minor consequence and have not been identified.

9.2 FACILITY CLASSES

Only one activity, a research reactor, is covered in this chapter. The accelerator is included in Chapter 10.

9.3 VA PROGRAMS FOR D&D

The VA does not have an identified D&D program.

9.3.1 VA Facilities

The VA operates a Triga Mark I reactor at the Omaha, Nebraska VA Hospital. The reactor was installed in 1959, and was still operating in 1978 (TIC78, Er79). The reactor is very similar to the Triga reactor used as the reference research reactor (Appendix A).

9.3.1.1 Status

Published information indicates the facility is still active (Er79). The projected operating lifetime is 40 years (Ko82).

9.3.1.2 Representative VA Facility

The facility is assumed to be similar to the reference research reactor described by Ko82. A summary for the reactor is given in Appendix A.

9.3.1.3 Existing Contamination

No information on the degree of contamination of the reactor was found, but it is assumed it is similar to the reference reactor.

9.3.1.4 D&D Procedures

The preferred D&D procedure for the research reactor is DECON; however, SAFSTOR could also be used (Ko82). In either case the reactor is defueled and the fuel and contaminated material are removed from the site for proper disposal. There is a choice as to removing the reactor vessel shortly after shutdown or sealing it in place to allow for partial decay of the activity. The reactor vessel should be removed prior to release of the site.

9.3.1.5 Characterization of the Wastes

The wastes from D&D of the VA reactor are projected to be the same as those from the reference reactor. The waste volume is estimated to be

35 m^3. The activity is assumed to be about 1,400 Ci, mostly activation products in the reactor vessel.

9.3.1.6 Residual Materials

If the reactor is operated for its full projected lifetime there will probably be minimal recyclable material. However, if it is shut down early, there is a possibility it could be sold or donated to another owner. The building can be decontaminated to allow unrestricted use.

10. PARTICLE ACCELERATORS

10.1 STATUS

10.1.1 Background

It is estimated that there are perhaps 1200 to 2000 atomic particle accelerators (USH80) operating within the U.S. Accelerators are found in every state. Accelerators find broad applications in physics, chemistry, radiobiology, medical radiation therapy, radiation processing and sterilization, industrial radiography and ion implantation for integrated electron circuit fabrication.

Accelerators range in physical size and particle beam energy from self contained portable linear accelerators rated at less than 1 MeV particle energy to custom built, major facilities which occupy many acres of land and produce particle beams of several hundred GeV, such as the 500 GeV proton accelerator at the Fermi National Laboratory in Batavia, Illinois (being increased to 1000 GEV, DOE79c).

Particle accelerators with beam energies above 100 MeV are devoted primarily to intermediate and high energy physics research. Of the large number of accelerators, only those which are under U.S. federal government support and control will be considered here for decontamination and decommissioning assessment and evaluation.

The large majority of U.S. accelerators are small units with less than 10 MeV acceleration energy capacity, which produces only small volumes and activity levels of radioactive waste. It is believed that the radioactive wastes from these small accelerators are generally exempt from current federal government regulations since the wastes are readily managed by natural decay and can be discharged within regulatory dilution requirements (USH80).

10.1.2 Location of Federally-Controlled Accelerators

Of the approximately 154 accelerators under government purview about one fourth of this total are located at U.S. National Laboratories in Oak Ridge, Brookhaven, Argonne and at University of California contractor sites. The locations of Federally controlled accelerators are given in Appendix C. This list is based on the indicated references, with limited updating by personal contacts. Some facilities may not be operating any more. Also, many small accelerators (less than 1 MeV) may not be reported.

10.2 REPRESENTATIVE FACILITIES (Reference Op79)

Accelerators may be classified in terms of the following general characteristics: particle accelerated, method of acceleration and application of the radiation produced. The earliest accelerators were custom-built and (with a few exceptions) intended for research in nuclear physics. As more advanced designs were developed, existing lower-energy accelerators were superseded and became supporting and training facilities, or were modified or supplemented for other uses such as nuclear chemistry or nuclear medicine. The Cockroft-Walton, Van de Graaff, and the Dynamitron, which are examples of early technology, have been used not only as primary research machines, but as injectors or preaccelerators for newer accelerators of higher energy.

Three different designs may be defined for the Van de Graaff. In one, a negatively charged, high potential electrode encloses a source that produces electrons. Particle energies are low enough that induced activity is absent or negligible, requiring no more than verification of low level of activity. Another design uses a positively charged, high-potential electrode housing a source that produces positively charged ions. Induced radioactivity may be present, depending on the ion accelerated and on the terminal potential that defines the ion energy. The third design incorporates a positively charged, high-voltage terminal at the midpoint of a supporting and accelerating structure. This configuration designated a Tandem Van de Graaff, is a large machine and induced radioactivity of beam components must be considered.

A second general class of accelerators operates on the resonance principle. The concept of a linear time-varying-field accelerator was developed about 1928 by Wideroe. In linear accelerators, the acceleration occurs along a series of straight path lengths and may be of the standing-wave or traveling-wave type.

The Clinton P. Anderson 800-MeV proton accelerator at Los Alamos Scientific Laboratory, commonly referred to as the Los Alamos Meson Physics Facility (LAMPF), is a standing-wave accelerator with injection from a 750-keV constant-potential accelerator.

The second kind of widely used linear accelerator is the traveling-wave type. This type is used generally for accelerating electrons.

Examples range from many MeV-range devices used for industrial and medical radiography and medical therapy to the 10-GeV machine at the Stanford Linear Accelerator facility.

The major drawback of linear accelerators is the requirement of increased linear length to produce higher energies. The two-mile Stanford accelerator represents a practical limit for linear-accelerator design.

Other accelerator designs use magnetic fields to produce confined-particle orbits (closed or spiral) to provide a greater spectrum of accelerated particles and energies in limited-space research facilities.

In a cyclotron, positive ions released from a centrally located source between two dees (e.g. shaped like a D) are accelerated by the electric field between the dees. The ions then coast at constant speed in the region within the dees, free of applied electric fields. A substantially uniform magnetic field bends the path into a semicircle, and when the interelectrode gap is again reached, the potentials have been reversed (resonance), leading to a second acceleration. This process continues and the ions spiral outward toward the bounds of the magnetic confinement as velocity increases. So-called isochronous cyclotrons of variable beam energy were developed using a preset but variable resonant frequency and magnet-trim coils. Above about 25 MeV the relativistic mass effects make the constant-magnetic-field-cyclotron principle inoperable. In response to this limit, accelerator designers developed the synchrotron (1945) and the synchrocyclotron (1946). The synchrocyclotron avoids the energy limitation of the fixed-frequency cyclotron by varying the resonant frequency of the electric field between the dees. For this reason, a synchrocyclotron is alternatively known as a frequency-modulated (FM) cyclotron. The beam current of a synchrotron is greatly reduced compared to a cyclotron, because groups of ions must be conducted through the resonant-frequency modulation. Though synchrocyclotrons have been built to accelerate protons up to 730 MeV (about 30 times the highest energy reached in cyclotrons), the time-averaged yield of particles is reduced by a factor of about 1000.

The oldest of the large machines still in operation are the synchrocyclotrons and cyclotrons. These are compact machines, characterized by a massive magnet surrounded with some combination of fixed and portable shielding. The accelerating structures have induced radioactivity and all of the machine and its shielding requires special handling because of induced activity. Some of these machines have been dismantled, others have been shut down, and some have been converted to uses other than physics research.

The alternating-gradient principle has also been applied to cyclotrons. It is known by varying names such as azimuthally varying field (AVF), fixed field alternating gradient (FFAG), sector focused, and radial or spiral-ridged in cyclotrons of solid-pole design and in the more complex separated-sector cyclotrons.

10.2.1 Categorization of Accelerators

A general method for categorizing particle accelerators is based upon the operational mode associated with the production and delivery of the particle beam. With this method, three general classes (Op79b) of accelerators may be identified as follows:

- I - Constant Direct Current (DC)
  - A - Direct Current Accelerators
    - Van de Graaff Generators
    - Cockroft-Walton Accelerators
    - Dynamitrons
  - B - Tandem Accelerators
- II - Cyclic or Incremental Beam Accelerators
  - Linear Accelerators
  - Cyclotrons
  - Synchrotrons
  - Synchrocyclotrons
- III - Magnetic Field Accelerators
  - Betatrons

10.2.2 Radiation Levels at Representative Accelerators

Radiation levels measured at representative accelerator facilities at various times after shutdown are summarized in Op79. A few weeks after shutdown these values range from very hazardous values in excess of 125 R/hr 1 ft from the surface of the UCLA 38-inch cyclotron to a few mR/hr in other accelerators. Generally, these radiation levels are associated with short-lived induced radioactivity and decrease rapidly with time.

10.3 EXISTING CONTAMINATION

10.3.1 Background

The primary factors that determine the magnitude of the radiological hazard to be expected in decommissioning an acccelerator facility include the type and size of the accelerator, the energy and beam current, the particle species accelerated, the age of the facility, and the use and history of the facility. These factors determine the levels of induced radioactivity in various components and systems and also the physical quantity of activated materials. The diversity in types, energies, and uses of accelerators results in health physics and waste management considerations that are essentially unique at each installation. Aside from the actual operating parameters of an accelerator, there are a number of other factors that will impinge on the problem. These include the accessibility of the accelerator to rigging and material handling equipment, the method of disassembly used on a particular accelerator, and the potential for reusability of either the accelerator components or the buildings.

Although the precise nature of the radiological contamination existing at a given accelerator depends on many considerations, residual radiation at an accelerator is due primarily to neutron induced activity. Furthermore, no surface or airborne contamination generally is found (Op79).

Estimates can be made for the total quantity of radioactivity contained in a proton accelerator by using approximations given by Go76. The method for estimating the residual radioactivity produced in an accelerator is based on equilibrium operation where the decay rate of radioactivity is equal to the production rate. The production rate is proportional to the accelerated beam intensity and energy. As a first approximation, for accelerators with a beam energy of a few hundred MeV, the saturation activity is equal to the beam intensity. Since

$$1 \quad A = 6.025\text{x}10^{12} \text{ protons/sec and}$$

$$1 \quad Ci = 3.70\text{x}10^{10} \text{ dis/sec,}$$

then a value of 160 Ci/ A results. This radioactivity potential is distributed among the various machine components and the experimental apparatus which intercepts the beam. For example, the fraction of the beam that activates a cyclotron magnet is probably in the range of 1 to 10 percent. Therefore, approximately 1.6 to 16 Ci of saturation activity from operations with a 1 A beam of protons is expected.

For very high energy accelerators (multi-GeV), the phenomenon of spallation, or star production, in which a multiplicity of secondary particles are produced, can result in varied activiation products. For example, a beam of 10^{12}, 400-GeV protons/sec is estimated to produce approximately 10 kCi of long-lived activity (Go76), which yields a ratio of about 1600 Ci per microamp of beam.

The estimation of radioactivity induced by high energy electron beams and the associated bremstrahlung has been reviewed by Sw79. The photons produced by electron beams produce radioisotopes by photonuclear reactions, the quasi-deuteron effect and photospallation at high energies. The components which absorb the electron and photon beams are subject to the highest activiation levels.

Table 10-1 is a summary of the long-lived isotope production data calculated for electron beams of energy 35 MeV and greater (Sw79). The percent of saturation attained for each isotope after a 25-year operating

TABLE 10-1
INDUCED RADIOACTIVITY FROM ELECTRON BEAMS

Target Material	Isotope Produced	Half Life (yr)	Saturation Activity (Ci/kW)	Percent of Saturation Activity for 25 Year Operation	Expected Activity (Ci/kW)
Concrete	Na-22	2.6	0.1	99.9	0.10
Aluminum	Na-22	2.6	0.28	99.9	0.28
	Al-26	7.3×10^5	8.8	0.0023	2.04×10^{-4}
Iron	Mn-54	0.85	0.59	100	0.59
Nickel	Co-57	0.74	5.9	100	5.9
	Co-60	5.27	0.1	96.2	0.096
Copper	Co-60	5.27	0.65	96.2	0.63
	Ni-63	100.0	0.45	17.0	0.077
	Zn-65	0.67	5.3	100	5.3

life has been calculated and is shown with the expected production in terms of curies per kilowatt of beam power. The long half-life isotope Al-26 is included to illustrate the fact that products with very long half-lives will generally not be a significant waste disposal problem.

Although the precise nature of the radiological contamination existing at a given accelerator facility is dependent upon design and operational factors, the large majority of the residual radiation found at an accelerator is due primarily to neutron induced radioactivity. Furthermore, surface and airborne contamination is generally negligible.

The radiation environment at a shut down accelerator facility is governed primarily by the induced activity present. Table 10-2 summarizes the potential for production of induced activity for various types of accelerated particles and various energy ranges, as taken from the National Bureau of Standards Handbook. For electrostatic positive-ion accelerators such as Van de Graaffs, Cockroft-Waltons, and Dynamitrons, radiation from induced activity is minimal. Other than beam line components and the accelerator column all other equipment can be treated as ordinary scrap metal. For small electron accelerators (small linacs, dynamitrons, Van de Graaffs, betatrons, etc.) induced activity is again low. Only segregation of active items is necessary.

For cyclotrons, synchrocyclotrons, and synchrotrons both equipment and building decontamination or demolition may be needed.

For the very high-energy proton linacs (e.g., the 800-MeV Los Alamos Meson Physics Facility), the levels of induced activity (considerably greater than 1000 R/h) in the primary target areas will require remote

TABLE 10-2

POTENTIAL FOR INDUCED RADIOACTIVITY BASED UPON PARTICLES ACCELERATED AND ENERGY

Source: (NBS70)

Particle	Energy Range (MeV)	Induced Radioactivity in	
		Target Area	Vicinity
Electrons	<1.7	None	None
Electrons	1.7 - 10	Limited	Very Slight
Electrons	>10	Probable	Suspect
Protons, He ions	<1	Limited	None
Deuterons, Tritons	1 - 10	Limited	Suspect
Deuterons, Tritons	Any	Probable	Suspect
All ions of Light Atomic Weight	>10	Certain	Suspect

dismantlement techniques unless a very long delay time is allowed prior to the start of decommissioning. The accelerator itself can probably be dismantled using manual techniques with the same health physics requirements as at a synchrotron or synchrocyclotron. The best approach from the health physics viewpoint might be to mothball the target areas for a long period; the length of time would depend on the actual activity levels and isotopes existing at the time of decommissioning. However mothballing entails the costs of continued security and surveillance.

The detailed distribution of isotopes produced in accelerator materials is a complicated function of the type and energy of the incident particle(s), beam intensity, beam transport efficiency, target elements, and the cross sections for the various reactions involved.

Most of the major structural components of particle accelerators generally consist of either iron or copper. Major exceptions to this are the use of depleted uranium and lead for certain shielding and collimation applications, and the use of aluminum for magnet windings.

10.3.2 Characterization of Contaminated Components

There are some components in any major accelerator facility that will become highly radioactive. These components constitute portions of the primary beam transport systems, target stations and beam stops which are directly impacted by the accelerated beam as part of normal operations. For the very high energy and high intensity accelerators, those components and structures in the vicinity of points of primary beam interaction will also be highly activated by secondary particles. In addition to these localized "hot spots", the main structure of the accelerator, primarily the magnet iron along with its copper or aluminum windings for circular machines, and copper drift tubes and tanks for linear accelerators will all contain a highly variable distribution of activation products. It can generally be assumed that all the permanent components within the primary shield enclosure or vault will have some degree of induced radioactivity. In addition, the walls of the shield vault itself may contain significant quantities of induced radioactivity. Other components may contribute to the radioactive waste volume. For example, cooling water systems may accumulate and concentrate radioactivated corrosion products. Vacuum systems, ventilation systems, and target transport systems also could present additional radioactively contaminated material.

It should be noted that for large accelerators the great bulk of the accelerator mass is contained in the magnet and drift tubes which do become radioactive. The average volumetric radioactivity level is generally small in large components, however.

Table 10-3 lists the major equipment categories to be found at a major accelerator facility. For complete D&D of a given facility the potential for direct or indirect radioactive contamination of equipment in these categories must be evaluated (Op79).

10.3.3 Typical Quantities of Radioactive Wastes for Selected Facilities

The estimation of the quantity of waste material with induced activity is a two part problem. The first part is the estimation of the amount and concentration of radioactivity. The second is the estimation of the total

TABLE 10-3

MAJOR EQUIPMENT CATEGORIES

Mechanical Equipment

Tanks

Support Structures

Compressors

Pumps

Piping & Vaulting

Water Processing

Moveable Shielding

Cryogenics and Refrigeration Equipment

Cryostats

Dewars

Transfer Lines

Helium Liquifiers

Refrigeration Evaporators

Refrigeration Liquifiers

Controls and Instrumentation

Transducers

Displays

Interlock Systems

Computers

Beam-Line Devices

Electrical Equipment

Magnets

Transformers

Switchgear

Rectifiers

Power Supplies

Cabling

Vacuum Equipment

High-Vacuum Pumps

Backing Pumps

Roughing Pumps

Vacuum Gauges

Vacuum Valves

Vacuum Pipes

mass and volume of material in which this radioactivity resides. The latter determine the true magnitude of the problem.

Table 10-4 shows the masses and residual activities of selected accelerators (Op79).

10.4 D&D PROCEDURES

The federal government has funded decommissioning of five accelerators: Two synchrocylotrons, one at the University of Rochester, the other at Carnegie Melon University; an Electron Accelerator at Cambridge; the Heavy-Ion Linear Accelerator at Yale and the Brookhaven Cosmotron (Op79, Op79a).

In these decommissionings, most system components including those having induced radioactivity were claimed for reuse, rather than disposal. The residual radioactive waste resulting from dismantling and decontamination was sent to commercial radioactive waste burial grounds (Op79, Op79a).

The operation of the 130-inch 250 MeV synchrocyclotron at the University of Rochester was terminated late in 1968. The accelerator was dismantled during the first five months of 1971. The steel main frame of the magnet was cut into blocks and shipped to the Fermi National Accelerator Laboratory for use as radiation shielding. The radioactive parts were removed from the site and buried at West Valley, New York. The highest exposure level encountered was 140 mR/h at the magnet-pole tips. The building was left intact for further use by the University. The cost of decommissioning (about $100,000) was borne by the AEC (Op79, Op79a).

The Cambridge Electron Accelerator, a 6-GeV electron synchrotron at Harvard, was shut down at the end of May 1973. Major components were

TABLE 10-4

MASS OF RADIOACTIVE WASTE FROM SELECTED ACCELERATORS

Source: Op79

Location	Energy (MeV)	Diameter or Length	Material (>1R/h @1m) (MT)	Reported Mass of Accelerator (MT)	Total Active Material (MT)	Estimated Amount of Activity (Ci)	Average Beam Current (μA)
Positive-Ion Cyclotrons and Synchrocyclotrons							
Duke U	15	31 in	--	--	--	7.6x10^{1}	30
UCLA	22	38 in	--	2.3x10^{1}	2.5x10^{1}	1.1x10^{2}	30
U of Colorado	28	52 in	--	9.0x10^{1}	9.9x10^{1}	7.6x10^{2}	160
ANL	40	60 in	4.8x10^{-2}	2.9x10^{2}	3.2x10^{2}	--	--
U of Washington (Seattle)	40	60 in	1.1x10^{-1}	1.1x10^{2}	1.2x10^{2}	--	--
Michigan State U	50	67 in	2.5x10^{-3}	2.0x10^{2}	2.2x10^{2}	1.7x10^{2}	20
NASA/Lewis	55	83 in	5.4x10^{-2}	2.3x10^{2}	2.3x10^{2}	2.3x10^{2}	25
LBL	60	88 in	1.4x10^{-2}	3.0x10^{2}	3.3x10^{2}	1.9x10^{3}	190
Texas A&M	60	88 in	0	2.7x10^{2}	3.0x10^{2}	2.9x10^{3}	285
Harvard U	160	95 in	4.2x10^{-1}	7.1x10^{2}	7.8x10^{2}	5.4	0.2
Lawrence Berkeley Lab (LBL)	730	184 in	--	4.3x10^{3}	4.7x10^{3}	6.2x10^{1}	0.5
NASA/SREL	600	197 in	2.0x10^{1}	2.6x10^{3}	2.9x10^{3}	2.0x10^{5}	2.0
Indiana U	225	272 in	--	2.0x10^{3}	2.2x10^{3}	--	--
Proton Synchrotrons							
Princeton-Penn	3,000	60 ft	--	1.4x10^{3}	1.5x10^{3}	5.1x10^{1}	0.1
LBL-Bevatron	6,200	100 ft	--	9.8x10^{3}	1.1x10^{4}	9.5x10^{2}	0.9
ANL-ZGS	12,700	180 ft	2.3x10^{1}	1.4x10^{4}	1.5x10^{4}	2.2x10^{2}	0.1
BNL-AGS	33,000	860 ft	6.0x10^{3}	1.8x10^{5}	2.0x10^{5}	2.2x10^{3}	0.4
FNAL	400,000	5000 ft	4.6x10^{5}	1.0x10^{4}	1.1x10^{4}	6.8x10^{3}	0.1
Electron Synchrotron							
Cornell U	12,000	820 ft	--	1.3x10^{2}	--	--	0.8
Electron Linacs							
ANL	35	30 ft	0	4.0x10^{1}	--	--	--
MIT Bates Lab	400	600 ft	--	--	--	--	--
SLAC	20,000	2 mi	--	--	--	--	30
Proton Linacs							
LAMPF	800	2600 ft	--	--	--	9.5x10^{4}	700
Electrostatic Accelerators							
ANL-Tandem	30	--	0	5.0x10^{1}	2.5x10^{-1}	--	--
U of Washington-Tandem	--	--	0	5.0x10^{1}	3.0x10^{-3}	--	--

assigned and shipped to other laboratories, but the title to some components was transferred to Harvard for the salvage value. Disassembly and demolition activities continued through July 1975. The highest induced radioactivity found at the facility was 100 mR/h at the linac converter. Activities up to 1 mR/h were found on the tunnel walls a year after shutdown. The total recorded dose equivalent resulting from the decommissioning was less than 0.67 man-rem. The cost of the decommissioning to ERDA was $735,000, including $96,500 paid to Harvard to assume responsibility for the final demolition activities (Op79, Op79a).

The Nuclear Research Center owned by Carnegie-Mellon University was closed in 1969. The 130-inch 440-MeV synchrocyclotron was dismantled in 1974 and 1975. All radioactive components were disposed of either by transfer within ERDA or burial as radioactive waste. Radioactive waste from the operation, which had been buried on site, was retrieved for reburial at Maxey Flats, Kentucky. Exposure levels up to 175 mR/h were encountered in the synchrocyclotron chamber. The site was decontaminated by removing all radioactive components, waste, and concrete in preparation for sale. The cost to ERDA was approximately $500,000 (Op79).

The Heavy-Ion Linear Accelerator at Yale University was dismantled during the six-month period beginning January 1975, immediately after cessation of operations. Most of the major components had been assigned to other laboratories and were shipped in conjunction with the disassembly. Induced radioactivity was present, but it did not result in significant exposure to personnel. Following the disassembly, the building was found to be radiologically clean. The $105,000 cost of decommissioning was the responsibility of ERDA (Op79).

The Brookhaven Cosmotron, a 3 GeV proton synchrotron, was shut down on December 31, 1966. The machine was kept in standby condition for one year after shutdown, during which time the experimental area was dismantled and much of the equipment was transferred to the Alternating Gradient Synchrotron (AGS) facility, also located at Brookhaven National Laboratory (BNL). After the year had elapsed, authorization to proceed with the dismantling of the Cosmotron itself was granted by the AEC, the owner of the machine. The removal of resuable equipment and components was performed on a spare-time basis by BNL personnel. The actual disassembly of the synchrotron ring magnets was done by contract technician labor over a three- or four-month period. The one-year waiting period resulted in a significant reduction of the induced-activity levels. The magnet segments, copper windings, vacuum chambers, and vacuum pumps were placed in the radioactive material storage area at BNL, where most of them remain todav. The presence of induced radioactivity in these items precluded their release to scrap dealers. A number of magnet blocks have been used as shielding at the AGS and more recently for experiments at the Fermi National Accelerator Laboratory. Because of the difficilty in removing the epoxy resin and fiberglass insulation bonded to the copper magnet windings, very few of these have been reused (Op79).

As an alternative to dismantlement, accelerators, especially smaller machines such as particle injectors, have often been transferred in a relatively intact form to other accelerator facilities. For example, the AGS 50-MeV proton linac injector was moved to the Lawrence Berkeley Laboratory for use as an improved injector to the Bevatron. The 2.2 GeV Cornell Electron Synchrotron was sent to Argonne National Laboratory for use as a proton booster. The 450 MeV University of Chicago synchrocyclotron was shipped to the Fermi National Accelerator Laboratory where it has served as a particle spectrometer in the Muon Laboratory, and the Princeton-Pennsylvania 3 GeV synchrotron was sent to Argonne National Laboratory.

Reference Op79 identifies 82 major accelerator facilities located in the U.S. that have been decommissioned as of early 1979.

10.5 CHARACTERIZATION OF RADIOACTIVE WASTES AND RESIDUAL MATERIAL

To estimate the potential mass and volume of radioactive waste materials resulting from the decontamination and decommissioning of federally controlled accelerator facilities, the following assumptions are made:

- All accelerators can be represented within their appropriate classification as given in Section 10.2.1 by a generic facility. Furthermore, radioactive waste generated by a given facility can be linearly scaled from the reference facilities.
- D&D activities at a major accelerator facility will not begin until at least one year after operation to minimize short-lived radiation handling problems.
- Present regulations and standards for classification of radioactive materials apply.
- The total operating lifetime for currently operating federally controlled facilities is 20 years.
- The introduction or commissioning of new federally controlled accelerators is not considered.
- The possible expansion (dilution) of radioactive waste volumes due to chemical toxicity is neglected.

- The major portion of the radioactive waste mass resulting from D&D activities is associated with very large facilities such as the proton synchrotrons, large cyclotrons and heavy ion linear accelerators.

Estimates for the mass and volumes of radioactive waste are shown in Table 10-5. The estimates span a broad range, depending upon individual characteristics of a given accelerator facility. Most of the radioactive accelerator material mass is iron and copper used in the accelerator structure and magnetic coils and steel and concrete associated with shielding materials. The principal long-lived radioisotopes of concern are Co-60, Na-22 and Fe-55. However, any material exposed to or contaminated by the accelerator beam may be radioactively contaminated. This includes materials in the accelerator buildings, soil beneath the buildings and even groundwater in the near vicinity.

It is possible to scale the radioactive waste mass with the beam energy of the accelerator. Figure 10-1 displays the radioactive waste mass associated with various generic types and specific major accelerators. A simple, approximate fit to the data is given by

$$\text{mass of radioactive waste (kg)} = 10^3 \times \text{accelerator energy (MeV)}$$

This formula should not be used to estimate waste volumes for small accelerators with a beam energy less than 10 MeV. For energies below 10 MeV the D&D wastes will be negligible.

If an average operating lifetime of the presently commissioned federally controlled accelerator facilities is assumed to be 20 years, then

TABLE 10-5

ESTIMATES OF MASS AND VOLUME OF RADIOACTIVE WASTE FROM ACCELERATOR FACILITIES*

Accelerator Type	Range of Mass of Radioactive Waste (metric tons per accelerator)	Range of Volume of Radioactive Waste (m^3 per accelerator)
Direct Current	<0.15	--
Cyclotrons, <20" diameter	0 - 27	0 - 7
Linear Accel., <600 ft (e^-)	0 - 27	0 - 7
Betatron	0 - 27	0 - 7
Cyclotrons, 20-50"	27 - 230	7 - 60
Cyclotrons, 50-100"	230 - 730	60 - 200
Linear Accel.,>600 ft (e^-)	230 - 730	230 - 730
Synchrotrons (e^-)	230 - 730	230 - 730
Cyclotrons, >100"	730 - 2000	200 - 570
Synchrotrons (proton) 60' - 100' diameter	2000 - 15,000	570 - 4000
Proton Sychrotons,>200 ft (proton)	15,000 - 200,000	4000 - 53,000
Linear Accelerator, >500 ft (proton)	15,000 - 200,000	4000 - 53,000

* Sources of information are Op79b for Direct Current Accelerators and Mu79 for all other accelerators. Betatrons were classed based on the energy of the machines.

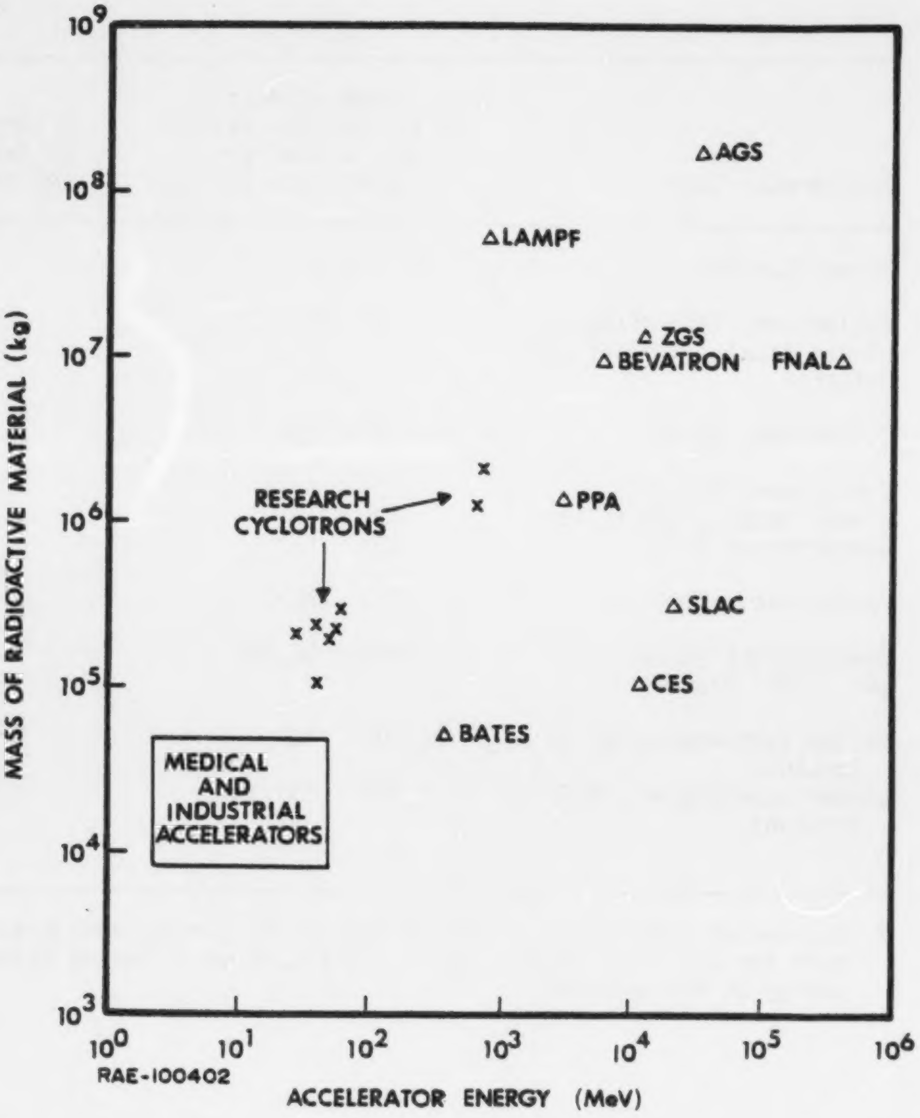

FIGURE 10-1. INDUCED ACTIVITY IN SELECTED ACCELERATORS

an estimate of the magnitude of radioactive waste volume and mass from D&D can be made for each decade. Table 10-6 lists estimated ranges of waste inventories from 1940 through 2000, when it is assumed that all presently existing federally controlled accelerator facilities will have been decommissioned. The data in Table 10-6 does not account for new facilities which may be established between now and the year 2000. The estimates span about an order of magnitude because they are based on similar broad ranges of estimates of waste from specific accelerator types, shown in Table 10-5.

Table 10-7 provides the ranges of total estimated volumes and masses of radioactive waste that will result from D&D of these facilities by accelerator type for the period 1940-2000. The D&D wastes for individual accelerators (i.e., Appendix C) can be estimated by use of Table 10-5 or the equation from Figure 10-1.

Two major alternatives exist in the decommissioning federally controlled accelerators. These alternatives would influence the mass of radioactive waste that would require disposal.

- Mothballing of the facility (with or without some dismantling of major components), after cleaning and removal of loose contaminated materials. This D&D option allows easy access for subsequent utilization, recycle or final disposal of the facility and its components.
- Entombment of the facility. This implies complete enclosure and sequestering of the facility with no anticipated future reentry or utilization. Because of the future increased value and scarcity of many of the accelerator component materials (e.g., copper, iron, metal alloying metals, etc), the non-retrievable disposal of accelerator components, particularly those with low-level contamination, may be unwise.

TABLE 10-6

POTENTIAL RADIOACTIVE WASTES PRODUCED FROM D&D OF ALL FEDERALLY-CONTROLLED ACCELERATOR FACILITIES

Decade	Range of Radioactive Wastes	
	Mass (MT)	Volume (m^3)
1941 - 1950	15 - 100	10 - 80
1951 - 1960	1500 - 10,000	900 - 5000
1961 - 1970	1000 - 2500	600 - 2000
1971 - 1980	2000 - 20,000	1000 - 6000
1981 - 1990	20,000 - 200,000	10,000 - 100,000
1991 - 2000	20,000 - 200,000	10,000 - 100,000

TABLE 10-7

ESTIMATED MASS AND VOLUME OF RADIOACTIVE WASTES FROM D&D OF FEDERALLY-CONTROLLED ACCELERATOR FACILITIES FROM 1940 TO 2000

Accelerator Type	Mass (MT)	Volume (m^3)
Linear Accelerators	25,000 - 200,000	10,000 - 100,000
Synchrotrons	15,000 - 200,000	10,000 - 100,000
Cyclotrons	1000 - 5000	1000 - 4000
Synchrocyclotrons	2000 - 5000	2000 - 4000
Betatrons	400 - 1000	200 - 600
Miscellaneous Units	100	10
Direct Current Machines	5	5
Neutron Generators	5	5
Tandem Accelerators	2	4
Ion Implanters	--	--
Cohesive Binders	--	--
Storage Rings	--	--
TOTAL	45,000 - 400,000	20,000 - 200,000

11. OTHER FEDERAL AGENCIES

11.1 INTRODUCTION

Several additional agencies are responsible for sites where there may be radioactive contamination. The identified agencies are:

- Department of Agriculture (DOA) - Experimental site(s) where simulated fallout studies with radioactive strontium were conducted (Me71).
- Environmental Protection Agency (EPA) - A laboratory in Montgomery, Alabama where surplus Ra-226 sources are stored and a laboratory in Las Vegas, Nevada, where a drum of uranium mill tailings was stored (DOE79a).
- National Space and Aeronautics Administration (NASA) - NASA previously operated three reactors at its Cleveland and Sandusky, Ohio facilities and an accelerator (21 MeV) at its Cleveland facility. All three reactors have been decommissioned. The accelerator is considered in Chapter 10.
- Tennessee Valley Authority (TVA) - TVA operates several power reactors, has more than 10 power reactors under construction or planned, owns an inactive uranium mill, and is involved in the phosphate industry (uranium is present in phosphate).

11.2 FACILITY CLASSES

The subject facilities vary from a drum of mill tailings to a decommissioned (SAFSTOR) test reactor, and power reactors.

11.3 AGENCY D&D PROGRAMS

The subject agencies do not have formal D&D programs. However, there is a proposed program for cleanup of the EPA facility.

11.3.1 Other Federal Agency Sites

The sites for each of the agencies is discussed separately below.

- DOA - Me71 reports that Sr-85 and Sr-89 were used in dry fallout studies at the Agriculture Research Service Station at Beltsville, Maryland. The reference is not clear on the matter, but Sr-90 may have been used at this or other locations. The fallout simulant consisted of 20 to 40 micrometer glass spheres. The area involved or residual contamination is not reported.

- EPA - Two sites are identified in DOE79a as having residual materials. A drum of uranium mill taiings was located at the Office of Radiation Programs, Las Vegas Facility, Nevada (ORP/LVF) facility. Also, the Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama, operates a repository for surplus Ra-226.

  The residual radioactive material at ORP/LVF was uranium mill tailings from the Vitro Site, Salt Lake City, Utah. About 0.1 m^3 of material containing about 1,000 pCi/g of thorium-230, radium-226, and associated progeny was stored in a sealed steel drum in a warehouse. The uranium content was less than 0.05 percent. The material was obtained for calibration of instruments and laboratory studies.

  The drum and the radioactive material, except for laboratory sample quantities, were transported to the Nevada Test Site in 1980 for interim storage. Part of the material, isolated in sealed cans, is now being used as a radon source for a radon chamber. The remainder of the material and the drum have been disposed of at the Nevada Test Site LLW burial site.

  A special facility was built at the EERF in 1964 for the storage of Ra-226 sources. The facility was part of the U.S. Public Health Services program to remove leaking, obsolute, and unused Ra-226 sources from circulation and ensure proper storage and disposal of the sources. The facility is designed for temporary storage and the U.S. PHS is responsible for arranging removal and final disposal.

  As of early 1982 about 9300 individual sources have been collected. Most of the sources range from 1 to 5 mCi, with the largest source being 5 Ci. The total inventory is about 130 Ci of Ra-226. About 60 new sources are received each year. Most of the sources are sealed, but there are some liquids, powders and leaking sources.

The facility is a specially designed concrete building. The sources are packaged in 30 cm (1 foot) high 30 cm diameter stainless steel containers. The containers are then placed in 30 cm diameter pipes, which extend below grade and and are capped with 90 cm concrete plugs.

The total amount of contaminated material is estimated to be 0.3 m^3.*

The EPA proposes to move the material in 1982 or 1983.

- National Aeronautical and Space Administration - NASA formerly operated a critical assembly (Docket No. 50-75, 100w) at its Cleveland, Ohio facility and a test reactor (Docket No. 50-30, 60 Mw) and mockup of the test reactor (Docket No. 50-185, 100 kw) at its Sandusky, Ohio facility. All of these reactors have been shut down and defueled. The reactors at Sandusky have been shut down (defueled) since 1973 in a semi-safe store condition (Ko82). The Cleveland reactor was dismantled in 1973, and the license was terminated (Er79).

  NASA is developing plans for dismantling both reactors at the Sandusky site (Ko82). Since some site and reactor cleanup work have been done it is difficult to estimate the resulting D&D waste volumes. However, since the reference test and mockup reactors are based on these reactors the reference values will be used. The D&D wastes for the test reactor are estimated to be about 200,000 Ci (they will have decayed to less than half of the original amount). The majority of this is tritium in the beryllium. The volume of waste is estimated to be about 1100 m^3 from the reactor and 3600 m^3 from retention basins, ditches, etc, if they have not been cleaned.

- Tennessee Valley Authority - TVA owns an inactive uranium mill at Edgemont, S.D. (included in Be82a), several operating power reactors, more than ten power reactors under construction or planned, and is involved in the phosphate industry (National Fertilizer Development Center) in Muscle Shoals, Al. The power reactors, which will involve a large amount of D&D wastes, are outside the scope of this evaluation. The phosphate facility, which is also outside the scope of this evaluation, is mentioned since uranium and its decay products are associated with phosphate.

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* Personal communication, Robert Callas, EPA, EERF, Montgomery, Al., February 10, 1982.

APPENDIX A

REFERENCE REACTOR FACILITIES

This appendix presents estimates of existing contamination and D&D wastes from reactors. This information is primarily based on Ko82 for the research, mock-up and test reactors. Information for the plutonium production reactors is based on Wa79.

Estimates of wastes for representative reactors are developed based upon the above references. These estimates are then used in pertinent sections of the text. This appendix only provides a summary of the information. The reader is referred to the original references for details and justification of assumptions.

Very little information is available on most of the government reactors. Therefore, it is emphasized that the estimates are only rough approximations of waste volumes.

Estimates are given for four classes of reactors:

1. Mock-up Reactors and critical assembles (power of less than 0.1 Mw).
2. Research Reactor: About 5 Mw or less; the reference reactor is 1 Mw; with a power integral of 740 Mw-days. Building is about 600 m2.
3. Test Reactor: Greater than 10 Mw; the reference reactor is 60 Mw, with a total power integral of about 100,000 Mw-days.
4. Plutonium Production Reactors.

A.1 Research, Test, Mock-Up Reactors

The reference mock-up facility and test reactor are based on the National Aeronautics and Space Administration Plum Brook Reactor facility. (Ko82). The research reactor is based on the Oregon State University TRIGA research reactor, supplemented by information from the Texas A&M TRIGA reactor.

After defueling most of the residual radioactivity is due to neutron activation products. Table A-1 indicates the elemental make-up of pertinent metals used in the reference reactors. Significant quantities of zirconium are apparently not used; therefore the long-lived activation product Zr-93 is not formed in significant quantities. The characteristics of the activation products and nuclear reactions leading to their production are summarized in Appendix D.

Based on the composition of material given in Table A-1, neutron flux distributions for the reference reactors and the structure of the reference reactors, and information from representative pressurized water and boiling water reactors the isotopic makeup of activation products is estimated (Ko82). The relative concentrations of various radionuclides in stainless steel (SS) and aluminum alloys and concrete for the research, test, and mock-up reactors are given in Tables A-2 to A-4. The concentrations in curies per cubic meter of material are given for the research and test reactors. The five columns on the right in each table give the fraction of the total original curie concentration (at shutdown) present as the subject radionuclide for the given time. For example, from Table A-2, at 100 years

TABLE A-1

ELEMENTAL WEIGHT FRACTIONS AND NEUTRONIC REACTIONS CALCULATED IN THE REFERENCE TEST REACTOR MATERIALS

Source: Ko82

Element	Element Weight Fraction in Material 304 Stainless Steel	356-T Aluminum	6061-T6 Aluminum	Lockalloy	Beryllium	Neutronic Reactions in Reactor Materials	Half-Life of Primary Nuclides (yr)
Aluminum		0.9035	0.9585	0.38	0.0009	Al-27 (n,γ) Al-28	
Beryllium				0.5137	0.996	Be-9 (n,α) He-6 $\rightarrow$ Li-6 (n,α) H-3	H-3 12.4
Cadmium					0.000002	Cd-112 (n,γ) Cd-113m, Cd-114 (n,γ) Cd-115m	Cd-113m 14.6
Carbon				0.001			
Chromium	0.20		0.0035				
Cobalt	0.001				0.000005	Co-59 (n,γ) Co-60m, Co-60	Co-60 5.27
Copper		0.002	0.004	0.0008		Cu-63 (n,α) Co-60, Cu-63 (n,p) Ni-63	Ni-63 92
Iron	0.649	0.006	0.007	0.002	0.0014	Fe-54 (n,γ) Fe-55, Fe-54 (n,p) Mn-54	Mn-54 0.83
Magnesium		0.004	0.012		0.0006		
Manganese	0.02	0.003	0.0015			Mn-55 $(n,2n)$ Mn-54	
Nickel	0.12					Ni-58 (n,γ) Ni-59, Ni-58 (n,p) Co-58m, Co-58, Ni-60 (n,p) Co-60, Ni-62 (n,γ) Ni-63	
Niobium	Trace	--	--	--	--	Nb-93 (n,γ) Nb-94	Nb-94 20,300
Phosphorus	0.00045						
Silicon	0.01	0.075	0.008	0.002	0.0008		
Sulfur	0.0003						
Titanium		0.002	0.0015			Ti-46 (n,p) Sc-46	
Zinc		0.003	0.0025			Zn-64 (n,γ) Zn-65	Zn-65 0.67
BeO + Al_2O_3				0.10		Be-9 (n,α) He-6 $\rightarrow$ Li-6 (n,α) H-3 Al-27 (n,γ) Al-28	

TABLE A-2

REFERENCE RADIONUCLIDE INVENTORIES, NEUTRON-ACTIVATED STAINLESS STEEL
REFERENCE RESEARCH AND TEST REACTORS

Source: Ko82

Radionuclide	Test Reactor Radioactivity Concentration at Shutdown (Ci/m^3)	Research Reactor Radioactivity Concentration at Shutdown (Ci/m^3)	Fractional Radioactivity at Decay Times of:				
			Shutdown	10 years	30 years	50 years	100 years
C-14	$2.97\text{x}10^{0}$ [b]	$9.22\text{x}10^{0}$ [b]	$1.75\text{x}10^{-5}$	$1.75\text{x}10^{-5}$	$1.74\text{x}10^{-5}$	$1.74\text{x}10^{-5}$	$1.73\text{x}10^{-5}$
Cr-51	$4.10\text{x}10^{4}$ [b]	$1.27\text{x}10^{5}$ [b]	$2.41\text{x}10^{-1}$	---[a]	---	---	---
Mn-54	$3.56\text{x}10^{3}$	$1.61\text{x}10^{4}$ [c]	$2.09\text{x}10^{-2}$	$3.49\text{x}10^{-6}$	---	---	---
Fe-55	$8.10\text{x}10^{3}$	$2.52\text{x}10^{4}$ [c]	$4.76\text{x}10^{-2}$	$3.63\text{x}10^{-2}$	$2.15\text{x}10^{-5}$	$1.27\text{x}10^{-7}$	---
Fe-59	$7.75\text{x}10^{2}$ [b]	$2.41\text{x}10^{3}$ [b]	$4.56\text{x}10^{-3}$	---	---	---	---
Co-58	$2.18\text{x}10^{4}$	$1.03\text{x}10^{5}$	$1.28\text{x}10^{-1}$	---	---	---	---
Co-60	$9.27\text{x}10^{4}$	$2.88\text{x}10^{5}$	$5.45\text{x}10^{-1}$	$6.33\text{x}10^{-2}$	$4.56\text{x}10^{-3}$	$3.28\text{x}10^{-4}$	$4.58\text{x}10^{-7}$
Ni-59	$1.80\text{x}10^{1}$	$5.59\text{x}10^{1}$ [c]	$1.06\text{x}10^{-4}$	$1.06\text{x}10^{-4}$	$1.06\text{x}10^{-4}$	$1.06\text{x}10^{-4}$	$1.06\text{x}10^{-4}$
Ni-63	$2.06\text{x}10^{3}$	$6.40\text{x}10^{3}$ [c]	$1.21\text{x}10^{-2}$	$1.14\text{x}10^{-2}$	$9.82\text{x}10^{-3}$	$9.07\text{x}10^{-3}$	$6.41\text{x}10^{-3}$
Nb-93m	$3.82\text{x}10^{-3}$ [b]	$1.02\text{x}10^{-2}$ [b]	$2.25\text{x}10^{-8}$	$1.35\text{x}10^{-8}$	$4.88\text{x}10^{-9}$	$1.76\text{x}10^{-7}$	$1.38\text{x}10^{-10}$
Nb-94	$4.25\text{x}10^{-2}$ [b]	$1.32\text{x}10^{-1}$ [b]	$2.50\text{x}10^{-7}$	$2.50\text{x}10^{-7}$	$2.50\text{x}10^{-7}$	$2.50\text{x}10^{-7}$	$2.49\text{x}10^{-7}$
Nb-95	$3.40\text{x}10^{0}$ [b]	$1.06\text{x}10^{1}$ [b]	$2.00\text{x}10^{-5}$	---	---	---	---
Totals	$1.70\text{x}10^{5}$	$5.61\text{x}10^{5}$	1.00	$1.11\text{x}10^{-1}$	$1.45\text{x}10^{-2}$	$9.52\text{x}10^{-3}$	$6.53\text{x}10^{-3}$

---

[a] Indicates a value of less than $1\text{x}10^{-10}$.

[b] Not calculated, inferred by analogy with Ni-59 activity.

[c] Based upon ratio of radionuclide to Co-60 observed in the reference test reactor calculation.

TABLE A-3

REFERENCE RADIONUCLIDE INVENTORIES, NEUTRON-ACTIVATED ALUMINUM REFERENCE RESEARCH AND TEST REACTORS

Source: Ko82

Radionuclide	Test Reactor Radioactivity Concentration at Shutdown (Ci/m^3)	Research Reactor Radioactivity Concentration at Shutdown (Ci/m^3)	Fractional Radioactivity at Decay Times of:				
			Shutdown	10 Years	30 Years	50 Years	100 Years
Sc-46	$1.96x10^{1}$	$9.80c10^{-2}$ [b]	$1.74x10^{-4}$	---[a]	---	---	---
Mn-54	$7.78x10^{2}$	$3.90x10^{0}$ [b]	$6.93x10^{-3}$	$1.15x10^{-6}$	---	---	---
Fe-55	$5.53x10^{4}$	$2.77x10^{2}$ [b]	$4.93x10^{-1}$	$3.74x10^{-2}$	$2.22x10^{-4}$	$1.31x10^{-6}$	---
Co-60	$2.72x10^{1}$	$1.36x10^{-1}$ [b]	$2.42x10^{-4}$	$6.48x10^{-6}$	$4.68x10^{-6}$	$3.37x10^{-7}$	$4.70x10^{-10}$
Ni-63	$6.74x10^{0}$	$3.37x10^{-2}$ [b]	$6.00x10^{-5}$	$5.67x10^{-5}$	$4.94x10^{-5}$	$4.30x10^{-5}$	$3.04x10^{-5}$
Zn-65	$5.61x10^{4}$	$2.81x10^{2}$	$5.00x10^{-1}$	$1.62x10^{-5}$	---	---	---
Totals	$1.12x10^{5}$	$5.62x10^{2}$	1.00	$3.75x10^{-2}$	$2.76x10^{-4}$	$4.46x10^{-5}$	$3.04x10^{-5}$

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[a] Indicates a value of less than $1.0x10^{-10}$.

[b] Based upon ratio of radionuclide to Zn-65 observed in the reference test reactor calculation.

TABLE A-4

REFERENCE RADIONUCLIDE INVENTORIES, ACTIVATED BIOLOGICAL SHIELD CONCRETE AT THE REFERENCE RESEARCH AND TEST REACTORS[a]

Source: Ko82

Radionuclide[c]	Test Reactor Radioactivity Concentration at Shutdown (Ci/m^3)	Research Reactor Radioactivity Concentration at Shutdown (Ci/m^3)	Fractional Radioactivity at the Reference PWR Decay Time of:[b]				
			Shutdown	10 Years	30 Years	50 Years	100 Years
Ar-39	1.2×10^{-3}	5.4×10^{-4}	1.1×10^{-3}	1.1×10^{-3}	1.0×10^{-3}	1.0×10^{-3}	8.8×10^{-4}
Ca-41	2.2×10^{-4}	9.8×10^{-3}	2.0×10^{-4}	2.0×10^{-4}	2.0×10^{-4}	2.0×10^{-4}	2.0×10^{-4}
Ca-45	1.1×10^{-1}	4.9×10^{-2}	1.0×10^{-1}	2.3×10^{-8}	---[b]	---	---
Mn-54	5.3×10^{-3}	2.4×10^{-3}	4.8×10^{-3}	1.0×10^{-6}	---	---	---
Fe-55	9.5×10^{-1}	4.2×10^{-1}	8.6×10^{-1}	6.6×10^{-2}	3.9×10^{-4}	2.3×10^{-6}	---
Co-60	2.1×10^{-2}	9.3×10^{-3}	1.9×10^{-2}	5.2×10^{-3}	3.7×10^{-4}	2.7×10^{-5}	3.7×10^{-8}
Ni-59	3.7×10^{-5}	1.7×10^{-5}	3.4×10^{-5}	3.4×10^{-5}	3.4×10^{-5}	3.4×10^{-5}	3.4×10^{-5}
Ni-63	4.4×10^{-3}	2.0×10^{-3}	4.0×10^{-3}	3.8×10^{-3}	3.2×10^{-3}	3.2×10^{-3}	2.0×10^{-3}
Totals	1.1	4.9×10^{-1}	1.0	7.7×10^{-2}	5.3×10^{-3}	4.1×10^{-3}	3.1×10^{-3}

---

[a] The radionuclides listed include only those whose half-life and/or initial concentration result in a significant contribution after one year of decay and/or one hundred years of decay.

[b] Dashes mean the fractional level of radioactivity was less than 10^{-10}.

[c] Activation products from rare earths (e.g., europium) are not included because of the lack of information. They may be important in certain cases.

the Nb-94 concentration for the test reactor is 0.04 Ci/m^3 (1.7x10^5 Ci/m^3 at shutdown x 2.49x10^{-7}).

Cobalt-60 is the most important activation product in SS (Table 2-2) for the first 10 years after shutdown. Nickel-59 and -63 become important after 10 years. However, their decay schemes minimize their health significance. With time Nb-94 becomes significant.

The production of Co-60 in aluminium (Table A-3) is less significant than its production in SS. Zinc-65 produces the majority of the early gamma activity in aluminum, but it has a short half life. Iron-55 is present, but its decay scheme minimizes its significance.

Cobalt-60 appears to be the most important activation product in concrete, based on the combination of production, half life, and decay scheme. However, the possibility of rare earth activation products (concentrations not known) should be recognized (e.g., Eu-152 and Eu-154).

The curie concentration for the mock-up reactor is scaled down by 2x10^{-6} times that for the test reactor, based on the power and operating time profile. The cores, except for fuel, on the mock-up and test reactor are identical.

One curie of C-14 is produced in the graphite reflector and thermal column of the research reactor. Over 95% of this is in the 0.36 m^3 of graphite in the reflector material inside the vessel.

Activation products produced in beryllium in the test reactor are given in Table A-5. Tritium, which is bound in the beryllium represents 90% of the produced activity. Cobalt-60 is the main contributor to the gamma activity. These values are scaled down by 2x10^{-6} for the mock-up reactor.

TABLE A-5

REFERENCE RADIONUCLIDE INVENTORY, NEUTRON ACTIVATED BERYLLIUM IN REFERENCE TEST REACTOR

Source: Ko82

Radionuclide	Radioactivity Concentration at Shutdown (Ci/m^3)	Fractional Radioactivity at Decay Times of:				
		Shutdown	10 Years	30 Years	50 Years	100 Years
H-3	8.28×10^{5}	9.01×10^{-1}	5.22×10^{-1}	1.70×10^{-1}	5.51×10^{-2}	3.31×10^{-3}
Mn-54	8.85×10^{1}	9.63×10^{-5}	1.61×10^{-8}	---[a]	---	---
Fe-55	2.52×10^{4}	2.74×10^{-2}	2.08×10^{-3}	1.23×10^{5}	7.22×10^{-8}	---
Co-60	6.55×10^{4}	7.13×10^{-2}	8.27×10^{-3}	5.96×10^{-4}	4.29×10^{-5}	5.98×10^{-8}
Cd-113m	1.28×10^{0}	1.39×10^{-6}	8.53×10^{-7}	3.30×10^{-7}	1.10×10^{-7}	1.02×10^{-8}
Cd-115m	9.39×10^{-3}	1.02×10^{-8}	---	---	---	---
Totals	9.19×10^{5}	1.00	5.32×10^{-1}	1.71×10^{-1}	5.52×10^{-2}	3.31×10^{-3}

---

[a] Indicates value less than 1.0×10^{-10}.

The quantity of activation products in various parts of the reactors are given in Tables A-6, A-7, and A-8 for the research reactor and Tables A-9, A-10, and A-11 for the test reactors, (excludes concrete). The values for the mock-up reactors can be scaled from the test reactor, Tables A-9, A-10, and A-11, by using a factor of 2×10^{-6}. These inventories are based on power integrals of 740 Mw-days and 100,000 Mw-days for the research and test reactors, respectively. This assumes a 5% operating cycle over a 40-yr lifetime for the research reactor and a 40% operating cycle over a 12-yr lifetime for the test reactor.

Additional information on volumes of wastes from D&D of the reference research and test reactors is summarized in Tables A-12 and A-13. The estimates are for activation products and fission products from corrosion products (crud) in the reactor system, concrete structural material, the hot cells, and labs. The radioactivity in the reactor and other structures, except for the hot lab and hot cells, is primarily due to activation products versus fission products. This is based on the assumption that there was no leaking fuel near the time of the reactor shutdown.

The corrosion products, surface decontamination, in the reactor piping are largely due to corrosion of activation products from the reactor system. The quantity is not added into the inventory since it is already accounted for in estimating the production of activation products.

The total inventories for the reference research and test reactor complexes are summarized in Table A-14. This summary is based on data from Tables A-6 to A-13. These inventories assume the reactors were defueled and the systems were flushed out. Cleaning up or removal of the coolant is considered to be part of the initial shutdown.

TABLE A-6

ACTIVATION PRODUCTS IN STAINLESS STEEL COMPONENTS FOR REFERENCE RESEARCH REACTOR

Source: Ko82

Stainless Steel Components	Mass (MT)	Volume (m^3)	Total Activity (Ci) Shutdown	Total Activity (Ci) At 10 years
Reflector Centering and Leveling Screws	1.0×10^{-3}	1.2×10^{-4}	1.06×10^{1}	5.32
Grid Plate Inserts and Hardware	4.8×10^{-3}	6.0×10^{-4}	2.75×10^{2}	1.38×10^{2}
Transient Rod Hardware	3.0×10^{-4}	3.7×10^{-5}	1.93×10^{1}	9.70
Control Rods (3 each)	9.0×10^{-3}	1.1×10^{-3}	5.46×10^{2}	2.74×10^{2}
Fuel Storage Rack Hardware	6.0×10^{-4}	7.5×10^{-5}	7.47×10^{-4}	3.75×10^{-4}
Rotary Specimen Rack Hardware	1.7×10^{-2}	2.1×10^{-3}	2.19×10^{2}	1.10×10^{2}
Beam Tube Bellows	1.3×10^{-2}	1.6×10^{-3}	1.47×10^{-1}	7.39×10^{-2}
Shadow Shields	3.4	4.2×10^{-1}	4.82×10^{-6}	2.42×10^{-6}
Outer Beam Tubes	6.5×10^{-2}	8.1×10^{-3}	1.83×10^{-9}	9.24×10^{-10}
Thermalizing Column Bolt Inserts	3.6×10^{-3}	4.5×10^{-4}	1.02×10^{-13}	5.15×10^{-15}
Totals			1.07×10^{-3}	5.37×10^{2}
Adjusted Totals[a]			1.42×10^{3}	7.77×10^{2}

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[a] Adjusted for inclusion of radionuclides not directly calculated.

TABLE A-7

ACTIVATION PRODUCTS IN ALUMINUM CONPONENTS OF REFERENCE RESEARCH REACTOR

Source: Ko82

Aluminum Components	Mass (MT)	Volume (m^3)	Total Activity (Ci) Shutdown	Total Activity (Ci) At 10 Years
Reactor Vessel (core zone)	1.3×10^{-1}	1.2×10^{-1}	6.16×10^{-5}	2.19×10^{-6}
Reactor Vessel (above core)	6.2×10^{-2}	Not Given	1.89×10^{-9}	---[a]
Reflector Platform	1.2×10^{-1}	4.6×10^{-2}	1.0	3.62×10^{2}
Reflector and Shroud	3.4×10^{-1} 1.0×10^{-1}	1.3×10^{-1} 3.7×10^{-2}	1.73×10^{1} 1.18×10^{-1}	6.12×10^{-1} 4.22×10^{-3}
Grid Plates	2.6×10^{-2}	9.4×10^{-3}	4.91	2.10×10^{-1}
Safety and Grid Adapter Plates	1.2×10^{-2}	4.4×10^{-3}	2.84	1.01×10^{-1}
Neutron Source Holder	1.8×10^{-3}	6.5×10^{-4}	2.69×10^{-1}	9.56×10^{-3}
Dummy Fuel Elements	8.5×10^{-3}	3.1×10^{-3}	1.27	4.49×10^{-2}
Transient Rod and Guide Tubes	1.3×10^{-3}	4.8×10^{-4}	3.74×10^{-1}	1.33×10^{-2}
Fuel Storage Racks (3 each)	3.3×10^{-2}	1.2×10^{-2}	2.23×10^{-4}	7.95×10^{-6}
Ion Chambers and Holders (4 each)	3.3×10^{-2}	1.2×10^{-2}	7.25×10^{-2}	2.58×10^{-3}
Rotary Specimen Rack	5.8×10^{-2}	2.2×10^{-2}	4.98	2.09×10^{-1}
Pneumatic Transfer System (in core)	2.0×10^{-3}	7.4×10^{-4}	2.98×10^{-1}	1.06×10^{-2}
Pneumatic Transfer System (piping)	1.6×10^{-3}	6.0×10^{-4}	7.86×10^{-7}	---
Central Thimble (in core)	3.6×10^{-3}	1.3×10^{-3}	1.16	4.12×10^{-2}
Central Thimble (piping)	7.0×10^{-4}	2.6×10^{-4}	---	---
Inner Beam Tubes (in core)	3.3×10^{-2}	1.2×10^{-2}	2.40×10^{-3}	8.53×10^{-5}
Beam Tubes (99 to 180 cm)	4.5×10^{-2}	1.7×10^{-2}	4.61×10^{-9}	---
Thermal Column (in vessel)	2.1×10^{-1}	7.8×10^{-2}	1.53×10^{-2}	5.44×10^{-4}
Thermal Column (outer)	4.1×10^{-1}	1.5×10^{-1}	6.94×10^{-8}	---
Thermalizing Column (in vessel)	4.5×10^{-2}	1.7×10^{-2}	3.49×10^{-3}	1.24×10^{-4}
Thermalizing Column (outer)	5.6×10^{-2}	2.1×10^{-2}	4.75×10^{-10}	---
Totals			3.65×10^{1}	1.3

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[a] Insignificant.

TABLE A-8

ACTIVATION PRODUCTS IN CARBON COMPONENTS REFERENCE RESEARCH REACTOR

Source: Ko82

Carbon Component	Mass (MT)	Volume (m^3)	Total Activity C-14 (Ci)
Reflector	5.90×10^{-1}	3.6×10^{-1}	1.02
Dummy Fuel Elements	1.96×10^{-2}	1.21×10^{-2}	6.67×10^{-2}
Thermal Column (within vessel)	1.1	6.8×10^{-1}	1.89×10^{-3}
Thermal Column (outside vessel)	2.71	1.69	2.69×10^{-8}
Thermalizing Column (within vessel)	1.39×10^{-1}	8.57×10^{-2}	2.69×10^{-3}
Thermalizing Column (outside vessel)	3.67×10^{-1}	2.27×10^{-1}	2.52×10^{-11}
Total			1.09

TABLE A-9

ACTIVATION PRODUCTS IN STAINLESS STEEL COMPONENTS FOR TEST REACTOR

Source: Ko82

Stainless Steel Components	Mass (MT)	Volume (m^3)	Total Activity (Ci)	
			Shutdown	At 10 Years
Thermal Shield, Outer Upper	5.65	7.03×10^{-1}	2.03×10^{-3}	5.25×10^{-5}
Outer Lower	4.10	5.10×10^{-1}	6.99×10^{-4}	1.46×10^{-5}
Middle Upper	4.70	5.85×10^{-1}	3.30×10^{-3}	7.84×10^{-5}
Middle Lower	3.80	4.73×10^{-1}	1.85×10^{-3}	9.50×10^{-5}
Inner Upper	3.76	4.68×10^{-1}	4.61×10^{-3}	1.70×10^{-4}
Pressure Vessel, Wall	9.23	1.15	1.24×10^{-3}	4.37×10^{-5}
Bottom	2.30	2.86×10^{-1}	2.88×10^{-7}	2.71×10^{-8}
Flow Guide, Upper	1.05	1.31×10^{-1}	1.96×10^{3}	2.89×10^{2}
Lower	5.14×10^{-1}	6.39×10^{-2}	1.27×10^{-1}	1.21×10^{-2}
Support	1.90	2.36×10^{-1}	2.60×10^{-5}	2.45×10^{-6}
Metering Plate	6.92×10^{-1}	7.36×10^{-2}	3.93×10^{2}	3.53×10^{1}
Control Rod, Upper Rollers	1.25×10^{-2}	1.55×10^{-3}	1.78×10^{3}	1.25×10^{2}
Drive Box	7.04×10^{-1}	8.76×10^{-2}	8.63×10^{-6}	8.13×10^{-7}
Miscellaneous Bolts	1.94×10^{-3}	2.41×10^{-4}	3.35×10^{2}	2.72×10^{1}
Instrumentation Thimble	Not Available		2.53×10^{4}	6.63×10^{3}
Fast Flux Facility	Not Available		7.28×10^{2}	1.23×10^{2}
Shim Rod Section	Not Available		2.20×10^{3}	5.79×10^{2}
Adjusted Totals[a]			4.49×10^{4}	1.13×10^{4}

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[a] Adjusted for inclusion of radionuclides not directly calculated.

TABLE A-10

ACTIVATION PRODUCTS IN ALUMINUM COMPONENTS TEST REACTOR
Source: Ko82

Aluminum Components	Mass (MT)	Volume (m^3)	Total Activity (Ci)	
			Shutdown	At 10 Years
Upper Grid, in Core	$9.37x10^{-2}$	$3.47x10^{-2}$	$3.89x10^{3}$	$1.46x10^{2}$
in Hot Storage	$9.37x10^{-2}$	$3.47x10^{-2}$	$1.16x10^{2}$	$3.77x10^{-1}$
Beam Tubes, V-2	$2.89x19^{-2}$	$1.07x10^{-2}$	$3.69x10^{2}$	$1.56x10^{1}$
HB-4	$1.72x10^{-2}$	$6.37x10^{-3}$	$1.29x10^{-1}$	$5.35x10^{-3}$
HB-5,6	$1.69x10^{-2}$	$2.51x10^{-2}$	$2.62x10^{3}$	$3.74x10^{3}$
HT-1	$6.79x10^{-2}$	$2.51x10^{-2}$	$2.62x10^{3}$	$1.12x10^{2}$
HT-2	$8.55x10^{-2}$	$3.17x10^{-2}$	$7.64x10^{2}$	$3.32x10^{1}$
HB-1,3	$2.20x10^{-2}$	$8.15x10^{-3}$	$8.36x10^{-1}$	$3.55x10^{-2}$
Far South Box Plate	$6.20x10^{-2}$	$2.30x10^{-2}$	$1.47x10^{2}$	6.43
Side Plate (2 each)	$1.00x10^{-1}$	$3.70x10^{-2}$	$7.43x10^{3}$	$2.67x10^{2}$
Lower Grid	$1.66x10^{-1}$	$6.15x10^{-2}$	$2.26x10^{4}$	$7.49x10^{2}$
VAFT Lower Section (3 each)	Not Available		$2.28x10^{3}$	$4.46x10^{2}$
VAFT, 68-03	Not Available		$2.80x10^{-1}$	---
69-01	Not Available		$2.00x10^{-3}$	---
Instrument Thimbles	Not Available		$2.00x10^{-3}$	---
Cadmium Control Rods Test Reactor (6 each)	Not Available		$9.17x10^{1}$	$2.46x10^{1}$
Totals			$4.03x10^{4}$	$1.80x10^{3}$

TABLE A-11

ACTIVATION PRODUCTS IN BERYLLIUM COMPONENTS TEST REACTOR

Source: Ko82

Beryllium Components	Mass (MT)	Volume (m^3)	Ci at Shutdown Including ^3H	Ci at 10 yr Total Activity
North Core Box Plate, in Core	$4.20x10^{-2}$	$2.27x10^{-2}$	$5.93x10^3$	$3.20x10^3$
in Hot Storage	$4.20x10^{-2}$	$2.27x10^{-2}$	$2.96x10^3$	$1.71x10^3$
RD Blocks (8 each)	$1.63x10^{-1}$	$8.81x10^{-2}$	$4.40x10^3$	$1.49x10^2$
RC Blocks (8 each)	$1.63x10^{-1}$	$8.81x10^{-2}$	$2.22x10^3$	$9.20x10^2$
RB Blocks (8 each)	$1.13x10^{-1}$	$6.11x10^{-2}$	$1.23x10^4$	$6.08x10^3$
RA Blocks (8 each)	$1.13x10^{-1}$	$6.11x10^{-2}$	$5.61x10^4$	$2.99x10^4$
LI, II Blocks, (8 each)	$5.44x10^{-2}$	$2.94x10^{-2}$	$4.00x10^4$	$2.77x10^4$
LA Blocks, (19 each)	$1.29x10^{-1}$	$6.98x10^{-2}$	$1.09x10^5$	$5.92x10^4$
R and L Block Plugs (11R, 5L)	Not Available		$1.66x10^4$	$8.37x10^3$
Flow Divider Plate	$4.09x10^{-2}$	$2.21x10^{-2}$	$1.76x10^4$	$1.00x10^4$
Be Control Rod (5 each)	$3.3x10^{-1}$	$1.78x10^{-2}$	$6.02x10^4$	$1.06x10^2$
Totals			$3.23x10^5$	$1.53x10^5$

TABLE A-12

OTHER RADIOACTIVE MATERIAL ASSOCIATED WITH RESEARCH REACTOR
Source: Ko82

Item	Estimated Surface (m^2)	Percent of Area Contaminated	Rubble Volume[a] (m^3)	Ci at Shutdown
Reactor Building (Concrete)				
Reactor Structure	31	100	4.6	[d]
Reactor Top	9.4	20	0.1	
Fuel Storage Pits (3)	0.5	100	0.1	
Pump House, Heat Exchanger Bldg, and Waste Storage Room				
Floor Pad	152	10	0.9	
Sump	45	100	2.4	
Annex				
Hot Cell	13.5	100	8.5[b]	20[c]
Hot Lab	40	10	0.2	
Hot Lab Sump	15	100	0.8	
Summary				
Activation Products				2.3
All Contamination			17.6	22.3

Crud in reactor piping, mostly Co-60: 0.1 to 1 mCi/m^2

---

[a] Based on a thickness of contaminated material of 5 cm.
[b] Volume includes total concrete volume of cell.
[c] Used twice the figures for the light-use reference facility: 8 Ci, Sr-90 and Y-90, 6 Ci, Cs-137; <1 Ci actinides.
[d] Blanks indicate negligible activity or it is included with other values.

TABLE A-13

OTHER RADIOACTIVE MATERIAL ASSOCIATED WITH TEST REACTOR
Source: Ko82

Material	Surface Area (m^2)	Percent of Area Contaminated	Rubble Volume[a] (m^3)
Concrete			
Reactor Bldg & Containment Vessel			
First Floor	2400	100	125
Reactor Well, dry annulus, canals, and other reactor related facilities	3500	100	180
Hot Laboratory Bldg			
Hot Cells (7)	581	40	12
Canals, off-gas cleanup room, valve pit, repair shop, sump	824	100	43
Decon. Room	12	100	1
Other Areas (tunnels, storage, etc)	815	50	21
Fan House (sump, pipe trench, etc)	71	100	4
Waste Building	290	25-100	8
Pump House			
Heat Exchanger Room	100	50	3
Office and Lab Bldg (sump and utility tunnel)	100	50	3
Other Facilities (hot and cold retention areas)	1700	50-100	200
Total Contaminated Concrete			600

Crud in Limited Sections of Reactor Piping; mostly Co-60; about 1 mCi/m^2

Hot Cells (volume of concrete included above; 40% of contamination on concrete, 60% on stainless steel).	12[b]

Reactor Site

Contaminated drainage ditches and soil[c]

---

[a] Based on removal of 5-cm thickness for contaminated concrete.

[b] D&D wastes from 7 cells. Total volume contains 14 Ci of activity, the major fraction of which is in 2 m^3 from the hottest cell. About 30% of the activity is Cs-137 and another 30% is Sr-90.

[c] Co-60, 20 pCi/g; Sr-90 and Cs-137, 10 pCi/g; Pu-239, 0.03 pCi/g.

TABLE A-14

INVENTORY OF RADIOACTIVITY IN RESEARCH AND TEST REACTORS

Source: Ko82

Material	Research Reactor		Test Reactor	
	Volume (m^3)	Total Activity (Ci)	Volume (m^3)	Total Activity (Ci)
Reactor				
Stainless Steel Components (Primarily shadow shields)	0.4	1400	6[a]	45,000
Aluminum Components	0.7	36	1[b]	40,000
Beryllium Components	None	None	0.5	323,000
Carbon Component (Primarily reflector)	3	1.1	None	None
Concrete Structural Components				
Activation Products	18	2	600	c
Fission Products	--	20	c	14
Heating, Ventilation, Cooling Systems	d	d	280	c
Waste Handling Equipment	d	c	2	c
Hot and Cold Retention Areas (tank and floor plates)	c	c	20	c
Fume Hoods	2	1	3	2
Hot Lab	None	None	1	c
Pump House Equipment	3[e]	c	33	c
Piping and Valves	8[e]	c	80	c
Soil and Concrete Pipe				
Emergency Retention Basin (Pond)	None	None	3000	<1
Ditches	None	None	100	
Concrete Culverts	None	None	330	
Soil under cold retention bldg	None	None	200	
Totals[f]				
Reactor	4	1440	7.5	408,000
Concrete and Auxillary Facilities	31	23	1020	16
Soil and Concrete Pipe	Minimal	Minimal	3630	1
Overall Total	35	1460	4660	408,000
Rounded Values Used in Text	35	1400	Concrete 4000 Reactor 1000	410,000

---

[a] Added over a cubic meter to account for items with unknown volumes.

[b] Added in about 0.7 m^3 because of items with unknown volumes.

[c] Values are insignificant or are included with other values (i.e., activation products in crud came from corrison of other material).

[d] Values unknown; assume to be insignificant.

[e] Contamination in the Research reactor is minimal. Ko82 doesn't give values. Assumed 0.1 of test reactor value.

[f] Values are rounded off.

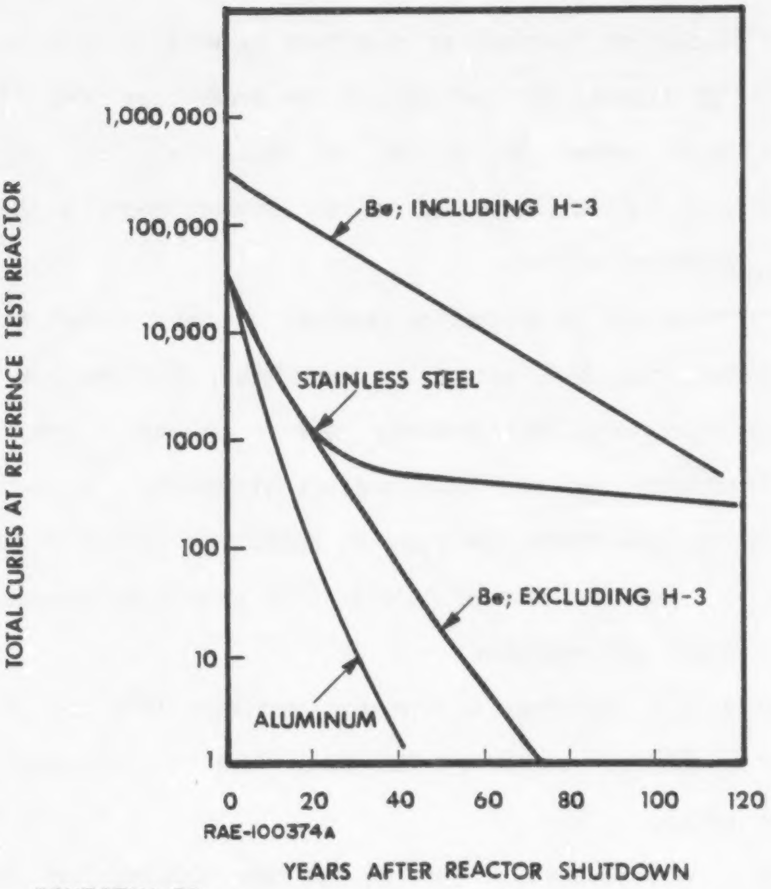
The radioactive inventory for the reference mock-up reactor is 2×10^{-6} times that of the test reactor or less than 1 Ci. The power level is such that the activation of concrete would be minimal. Therefore, the estimated volume is about 10 m^3, or less.

For the reference research reactor essentially all of the activation products at the time of shutdown are due to the stainless steel components. More than half of this activity is due to Co-60 at time of shutdown and ten years after shutdown (see Table A-2). At 100-years Ni-59 and Ni-63 contribute the major fraction of the radioactivity. However, because of the respective decay schemes Nb-94 (2×10^4 year half life) is the most significant radionuclide for external gamma exposure at periods of about 100 years. Carbon-14 from the carbon components also is important as a potential environmental contaminant because of its long half life.

For the reference test reactor the stainless steel (SS) and aluminum components result in similar quantities of activation products at the time of shutdown (Table A-14). A major fraction of the activity in SS is again due to Co-60, which has a longer half life (5.26 years) than either Fe-55 (2.6 years, also doesn't have gamma) or Zn-65 (245 days) which are the main contributors to the aluminum activation products. As for the research reactor, Nb-94 becomes important at time frames of 100 years. The largest contribution of activation products to the reference test reactor is from beryllium. However, about 90% of the beryllium contribution is tritium. The production of Co-60 (cobalt in the beryllium alloy) in the beryllium materials is similar to the amount of cobalt-60 produced in the SS materials.

Figure A-1 illustrates the decay of the activation products with time for the test reactor. The time profile would be similar for the mock-up reactor. The decay of the inventories given in Table A-14 can be estimated by using the factors in Tables A-2 to A-5.

There is very little information on the chemical and physical form of the radioactivity. Most of the activity is activation products tied up in the metal (stainless, aluminum or beryllium) matrix where it is produced. This is also true for the tritium produced in the beryllium and carbon-14 formed in the carbon. It has been observed that even when cutting the beryllium under water with a torch, very little tritium was released (Ko82).



SOURCE: Ko82

FIGURE A-1. TIME DEPENDENCE OF TOTAL RADIOACTIVITY IN NEUTRON-ACTIVATED REACTCR CONPONENTS FOLOWING FINAL REACTOR SHUTDOWN

A.2 PRODUCTION REACTORS

The reference production reactor is patterned after the deactivated Hanford production reactors as described by Wa79. There is very limited unclassified information available on the production reactors and although designs have changed the volumes of waste material and inventory of radionuclides for the reference reactor should generally characterize the active production reactors.

The three active production reactors at the Savannah River Plant are heavy water moderated reactors. Therefore, although they do not have graphite moderators they probably have a peripheral graphite moderator (0.3m thickness) and more core support structure. While there is less graphite for C-14 production there is production of H-3 in the heavy water moderator. However, most of this tritium should be removed with removal of the coolant and moderator.

Table A-15 indicates an inventory estimate from one of the inactive Hanford (graphite) reactors. The power level is estimated to have been 2000 Mw (Wa79).

Table A-16 presents a general estimate obtained by using Co-60 and C-14 production estimates for test reactors from Section A-1 and estimates of volumes of material from Wa79. Wa79 indicates most of the activity is Co-60 and C-14, but does not indicate the respective values. Based on Table A-16 it appears most of the reactor activity is C-14.

Table A-17 summarizes values from Tables A-15 and A-16 to characterize the reference production reactor facility. A power output of 2000

TABLE A-15

HANFORD PRODUCTION REACTOR DECOMMISSIONING
Source: Wa79

Facility/Component	Approximate Inventory (Ci)
Reactor Block	35,000
Control Systems	50
Fuel Handling/Basin	100
Retention Basin System	90
Ground Disposal Facilities	2,000
Other Misc. Systems	10
	37,250

TABLE A-16

ESTIMATE OF ACTIVATION PRODUCTS IN PRODUCTION REACTOR

Section of Reactor	Volume of Section (m^3)	Volume of Specific Material		Activation Level (Ci/m^3)	Activity (Ci)
		Material	(m^3)		
Graphite Core (Moderator)	822	Carbon	780[b]	50[a]	C-14 39,000
		Al fuel tubes in graphite	41[b]	27[c]	Co-60 1,107
Thermal Shield	94	Steel	94	0.006[d]	Co-60 0.6
Biological Shield	1160	Steel	580[e]	0.006[d]	Co-60 3.5

Totals:

C-14	39,000
Co-60	1,110

---

[a] Estimated from Ko82 (Table A-8 this report) assuming 5 Ci/m^3, based on dummy fuel elements for the research reactor and a twenty-year integral operating period versus a 740-day period for the research reactor.

[b] Assumed 5% of core volume comprised of Al fuel tubes.

[c] Taken from Ko82 (Table E.2-2), this report, Table 3-3 for test reactors.

[d] Taken from Ko82 (Tables E-2.1 and E.2-5), Tables A-2 and A-9 this report. The value is the Co-60 production for the inner thermal shield of the test reactor.

[e] Biological shield is composed of alternate layers of masonite and steel. It is assumed to be 50% steel.

TABLE A-17

REFERENCE PRODUCTION REACTOR INVENTORY AFTER DEFUELING AND FLUSHING REACTOR

Component	Volume[a] (m^3)	Activity[b] (Ci)
Reactor		
Moderator		
Graphite	780	39,000 (C-14 or H-3)[c]
Core Structure	40-100	1,000-10,000 (Co-60)[d]
Thermal Shield	100	1 (Co-60)
Biological Shield	600	5
Auxillary Systems		50
Control Systems		
Fuel Handling/Basin	200	90
Ground Disposal Facilities[e] and Soil Contamination	10,000	20 Mixed FP, TRU, Co-60
Totals (estimates, not summations)		
Reactor and Auxillaries	1,800	39,000 C-14 or H-3
Soil	10,000	5,000 Co-60 20 Mixed

---

[a] Volume estimates based on dimensions from Wa79.
[b] Radionuclides of over 1 year half-life. Assumes minimal fission product contamination of reactor.
[c] Basic values are predicted on a graphite moderator, and production of C-14. There will be much less graphite in a heavy water reactor. However, the tradeoff is probably in tritium production in the heavy water and beryllium (if beryllium is used in the core structure).
[d] The lower value is for Co-60 from aluminum in a graphite moderated reactor; little core structure. The higher value is an estimate for the heavy water reactors.
[e] Gross estimate, based partially on test reactor, assumes cribs and seepage basins were not used extensively.

Mw is proposed. An operating life of 40 years is estimated. The operating lifetime is more a function of changing technology, improved production ratios for new reactor designs (G155)and need than limits to the operable lifetime.

APPENDIX B

DOE FUEL REPROCESSING FACILITIES

Fuel reprocessing entails the recovery of plutonium and uranium from spent nuclear reactor fuel. The spent fuels reprocessed at DOE facilities are from reactors with functions ranging from plutonium production to ship propulsion. Generally, spent fuel from commercial power reactors is not processed at DOE facilities. Except at the Idaho Chemical Processing Plant the Purex process has been in use at all DOE reprocessing facilities.

In this country the first reprocessing efforts utilized the bismuth phosphate process (Be57) for recovering plutonium from irradiated natural uranium. The bismuth phosphate process is a precipitation process. The first solvent extraction process applied to reprocessing on a large scale was the redox process (Be57). The redox process was soon replaced with the Purex process in the mid 1950's. Since that time the Purex process has been used for reprocessing natural uranium and low enrichment fuels. Highly enriched fuels are reprocessed via a dual solvent process (Lo67 and Ho71).

Since the facilities discussed below are defense related, a number of difficulties have been encountered in obtaining information about them. While describing the processes and the structures to varying degrees, documents pertaining to the DOE reprocessing facilities generally do not contain information required for estimating decommissioning and decontamination waste volumes in the same detail available for commercial facilities. However, Sc77 is very useful in obtaining volume estimates for the DOE facilities.

The facilities discussed below are, in order, the Idaho Chemical Processing Plant (ICPP) at the Idaho National Engineering Laboratory (INEL) Idaho Falls, Idaho, the Savannah River Plant Chemical Separations Facilities, Aikin, S.C., and the 200 area facilities at Hanford, Wa. Considerably more information was available for the ICPP than for the other two sites and the ICPP section is developed in more detail. The ICPP does not utilize the Purex process used at Savannah River and Hanford, but it does use a similar solvent extraction process. The ICPP reprocesses highly enriched fuels while the Hanford facilities, involved with plutonium production, do not. The Savannah River Plant does both.

B.1 THE IDAHO CHEMICAL PROCESSING PLANT

The Idaho Chemical Processing Plant (ICPP) is located near Idaho Falls, Idaho on the Snake River plain in southeastern Idaho. The ICPP is part of the Idaho National Engineering Laboratory and is operated by the Exxon Nuclear Idaho Company, Inc., for the DOE, with the primary purpose of reprocessing irradiated high enrichment nuclear fuels. In addition to spent fuel from ship propulsion reactors and research reactors, other fuels such as High Temperature Gas Reactor fuel are or will be processed. Reprocessing has been carried at this site for approximately 30 years.

B.1.1 Reprocessing at ICPP

The ICPP process (Ho71 and ERDA77) is similar to the redox process (Be57). Since fuels processed at ICPP have a low plutonium content, the plutonium partitioning step is eliminated. The process flowsheet is shown in Figure B-1.

Irradiated fuel is received at the Fuel Storage Facility (FSF). The fuel arrives in heavily shielded casks and is transferred from the casks to the Fuel Storage Basin where it is stored under water. When the fuel is to be processed it is transferred to the process building. Here the fuel cladding is chemically removed in one of several dissolvers, depending on the type of fuel and cladding. The fuel is then dissolved in mineral acid. The resulting aqueous solution contains uranium, fission products and small quantities of transuranics. This solution is directed to the first extraction cycle illustrated in Figure B-2. Here the solution is fed into an extraction column where the uranium is preferentially extracted into an organic solvent phase consisting of 5 percent tributyl phosphate (TBP) in dodecane. The bulk of the fission products remain in the aqueous raffinate. The raffinate is directed to high-level waste (HLW) treatment. The uranium-bearing organic phase is then directed to a scrubbing column where traces of fission products are removed. Next the extract is passed through a stripping column where the uranium is stripped into a dilute aqueous nutric acid solution. This solution is then directed to a wash column where traces of TBP are removed and, finally, to an evaporator. The extraction-scrubbing-stripping processes are repeated two more times in second and third cycles. The solvent for these cycles is hexone. In the second cycle scrubbing, ferrous sulfamate is introduced in order to reduce the transuranics (Np, Pu) present. The transuranics in their reduced state are scrubbed from the solvent. The purified uranyl nitrate solution is

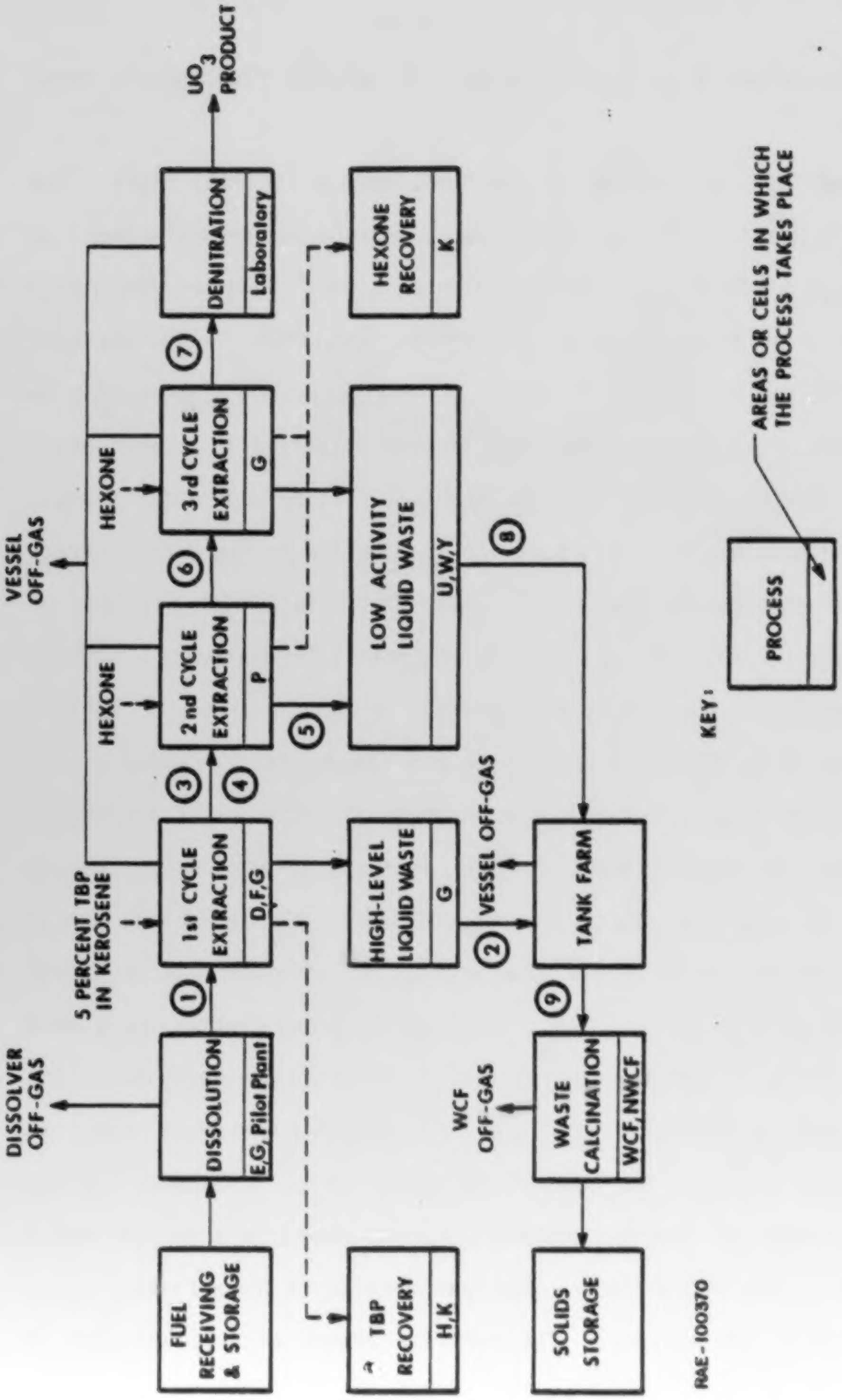

FUEL RECEIVING & STORAGE
DISSOLUTION
E,G, Pilot Plant
DISSOLVER OFF-GAS
①
5 PERCENT TBP IN KEROSENE
1st CYCLE EXTRACTION
D,F,G
TBP RECOVERY
H,K
③
④
HEXONE
2nd CYCLE EXTRACTION
P
⑤
VESSEL OFF-GAS
⑥
HEXONE
3rd CYCLE EXTRACTION
G
⑦
DENITRATION
Laboratory
UO3 PRODUCT
HEXONE RECOVERY
K
HIGH-LEVEL LIQUID WASTE
G
LOW ACTIVITY LIQUID WASTE
U,W,Y
⑧
②
VESSEL OFF-GAS
TANK FARM
⑨
WASTE CALCINATION
WCF, NWCF
WCF OFF-GAS
SOLIDS STORAGE
KEY:
PROCESS
AREAS OR CELLS IN WHICH THE PROCESS TAKES PLACE
RAE-100370

FIGURE B-1. ICPP PROCESS FLOWSHEET

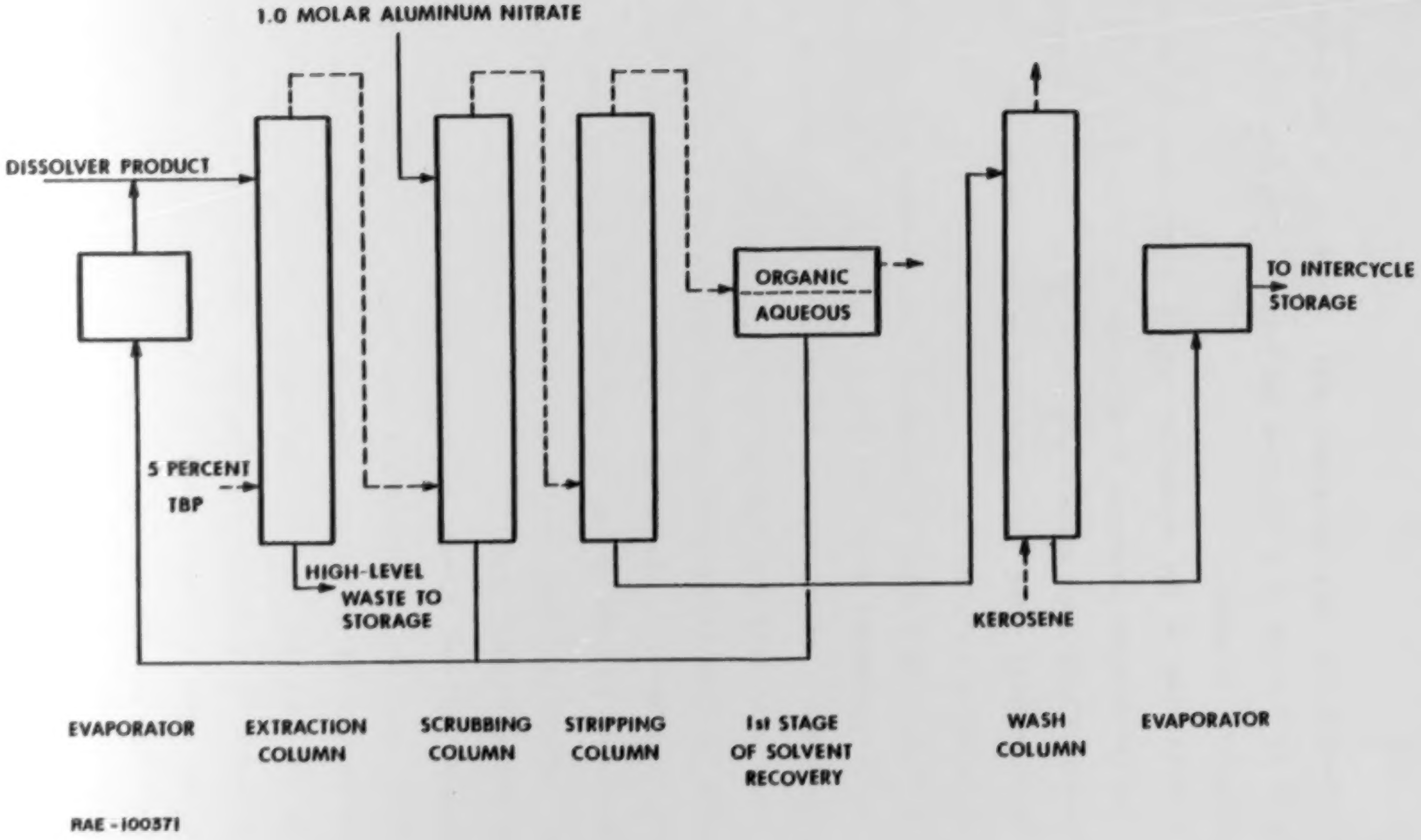

1.0 MOLAR ALUMINUM NITRATE
DISSOLVER PRODUCT
ORGANIC
AQUEOUS
TO INTERCYCLE STORAGE
5 PERCENT TBP
HIGH-LEVEL WASTE TO STORAGE
KEROSENE
EVAPORATOR
EXTRACTION COLUMN
SCRUBBING COLUMN
STRIPPING COLUMN
1st STAGE OF SOLVENT RECOVERY
WASH COLUMN
EVAPORATOR
RAE-100371

FIGURE B-2. FIRST EXTRACTION CYCLE

stored in geometrically safe containers until it is to be denitrated. Denitration is carried out in a fluidized bed reactor. The product, solid UO_3, is packaged for shipment.

The solvents used in the extraction require decontamination before recycle. The TBP-dodecane undergoes three washes in dilute nitric acid, sodium carbonate solution, and again dilute nitric acid. Degraded dodecane is first decontaminated using steam distillation and then burned. The hexone is recovered by distillation.

The high-level liquid waste is stored in tanks equipped with cooling coils and reflux condensers until its activity has decreased to a level permitting treatment. The low activity liquid wastes are concentrated as stored in tanks until they are directed to the calcination facility. At the calcination facility liquid wastes are calcined and the solid waste is pneumatically transferred to the solids storage bins. The calciner off-gases are separated from the solids in a cyclone, and directed through a spray tower, venturi scrubber, silica gel adsorbers and filters before being vented through the main stack.

The dissolver off-gas streams are routed through a reflux condenser and entrainment separator, a demister, a superheater, and a HEPA filter before discharge into the main stack. Some dissolver off-gas streams can be routed to the Rare Gas Facility (RGF) where radioactive krypton and xenon are recovered via cryogenic distillation. Ventilation air from the reprocessing and waste treatment areas is filtered through a deep bed fiberglass prefilter and HEPA filters.

B.1.2 Contaminated Facilities

Structures at the ICPP which are likely to require extensive decontamination are the Fuel Storage Basins, the Peach Bottom Fuel Element Storage Facility, the Fuel Processing Facility, the Hot Pilot Plant, the Waste Treatment and Atmospheric Protection System Facilities, HTGR Facilities adjacent to the Hot Pilot Plant, the Waste Calcination Building and the New Waste Calcining Facility, the Analytical and Decontamination Facility, and the Tank Farm. In addition, areas in the High Bay Engineering Laboratory, the Low Bay Engineering Laboratory, and denitration facilities in the laboratory building may require some decontamination. It is likely that in the lifetime of the ICPP some of these structures will undergo modification and some may be decontaminated and dismantled.

B.1.2.1 Fuel Storage Basins

Major Structures at the E-shaped Fuel Storage Basins include the North, Center and South Storage Basins, the loading and transfer pool, a 25,000 gallon sludge collection tank, a cask decontamination pad, and new and old filter stations. The North and the Center Storage Basins are each 40 ft x 60 ft x 21 ft and the South Storage Basin is 40 ft x 80 ft x 21 ft. The North and Center Basins and the Transfer Basin are covered with steel grating and have buckets of fuel suspended from yokes which ride on overhead monorails. The South Basin is open and fuel elements are stored in fuel storage racks. The basins are assumed to be lined with stainless steel.

Prior to 1963 fresh basin water was continually added while an equal amount was discharged directly to the ground through a manhole outside the building. From 1963 to 1966 the basin water was processed through an ion-exchange system prior to discharge into the manhole. In 1966 discharge was discontinued and the ion-exchange effluent is now being returned to the basins. A new basin particulate filter system capable of processing the entire basin water (1.5 million gallons) in 24 hours has replaced the old filter system (250 gpm). Filter backwashes originally were routed to two 5 ft x 5 ft x 30 ft settling basins. They are currently routed to the 25,000 gallon sludge collection tank.

B.1.2.2. The Peach Bottom Dry Storage Facility

The Peach Bottom Dry Storage Facility is composed of 46 storage vaults spaced on 30-ft centers in a square array covering an area approximately 200 ft x 350 ft. Each vault is 30 inches in diameter and approximately 20 feet deep and can accommodate one complete shipment of Peach Bottom I Core 1 fuel sealed in canisters. The vaults are carbon steel lined and have 2 feet of sand and cement grout at the bottom. A concrete pad, 8 ft x 1 ft x 1 ft, is poured around the top of each vault. The extent to which this facility will be contaminated at closure is not known but for this assessment it is assumed to all be waste.

B.1.2.3 Fuel Processing Facility

Fuel reprocessing is carried out in this facility. The building dimensions are approximately 100 ft x 240 ft x 90 ft. The building is divided into a number of separate process areas or cells. A number of the cells are partially or completely lined with stainless steel. For the purposes of this assessment the following cell equipment configuration is assumed (Ho71, ERDA 77). The letters correspond to processes designated in Figure B-1.

- A cell contains equipment for uranium salvage in conjunction with the HTGR fuel reprocessing.
- B cell contains waste handling equipment for the HTGR fuel reprocessing.
- C cell contains a concentrator for the first extraction cycle product in HTGR fuel reprocessing.
- D cell contains the first cycle extraction equipment for HTGR fuel reprocessing.
- E cell contains two dissolvers and miscellaneous tanks. One dissolver is for the semicontinuous dissolution of zirconium fuels in hydrofluoric acid. Auxillary equipment for this dissolver includes a reflux condenser and a caustic scrubber. The other dissolver is for the aqua regia dissolution of stainless steel fuels. It has a reflux condenser but no scrubber.
- F cell contains equipment for a small scale TBP extraction process and is out of service.
- G cell and H cell contain the equipment for continuous processing. This equipment includes two continuous dissolvers with reflux condensers for aluminum alloy fuels; the first cycle extraction column, aqueous scrubber, aqueous stripper, and organic wash column; four 2500-liter feed tanks; two 2500-liter aqueous raffinate tanks; product evaporator; and three mixer-settler tanks.
- J cell is used for salvaging uranium from various process steps and contains two salvage tanks, an evaporator, and two evaporator product holding tanks.
- K cell contains the steam still and tankage for hexone recovery and the steam stripper and tankage for the first extraction cycle solvent.

- L cell contains equipment for the recovery of radium. It is out of service and the equipment is decontaminated.
- M cell is empty.
- N cell is used for the intercycle storage of uranium. It contains geometrically safe uranium storage tanks.
- P cell contains the second extraction cycle columns and auxillary equipment.
- Q cell contains the third extraction cycle columns and auxillary equipment.
- R cell and S cell contain equipment for a fourth extraction cycle and a product recovery tank.
- T cell contains solvent pumps and hexone storage tanks.
- U cell, W cell, and Y cell contain tankage for collecting, sampling, and concentrating the aqueous raffinate from the second, third and fourth extraction cycles prior to routing to the tank farm.
- V cell is the health physics station and X cell is a plutonium laboratory.
- Z cell is used for the storage of the product uranyl nitrate solution.

B.1.2.4 Hot Pilot Plant

Four cells in the Hot Pilot Plant are used in the HTGR fuel reprocessing efforts. These cells are used for headend processing, including fuel handling, incineration and dissolution. An adjacent structure has a cell for liquid product loadout and off-gas cleanup.

A fifth cell in the Pilot Plant contains equipment for the electrolytic dissolution of EPR II spent fuel cermets. The electrolytic dissolver product is processed in the main process building facilities.

B.1.2.5 Waste Treatment Facility

Major process systems housed in this building include the Process Equipment Waste (PEW) System and the Rare Gas Facility. The PEW equipment consists of tankage for receiving and storing low-to-intermediate activity liquid wastes from the ICPP facility, an evaporator with a caustic scrubber and condenser, two overhead receivers, two ion exchange columns, and a bottoms receiver.

The Rare Gas Facility consists of cryogenic distillation apparatus for the recovery of radioactive krypton and xenon from dissolver off-gas streams.

B.1.2.6 Analytical and Decontamination Facility

The Analytical and Decontamination Facility consists of the Remote Analytical Facility, the Multicurie Laboratory, the Service Analysis Laboratory, and a decontamination pad. The Remote Analytical Facility contains an alpha-gamma cave and thirty boxes for remote procedures. The Multicurie Laboratory is heavily shielded, permitting bench scale procedures not possible in the Remote Analytical Facility. Routine work involving warm solutions is carried out in the Service Analysis Facility.

B.1.2.7 Calcining Facilities

The Waste Calcining Facility (WCF) was built to demonstrate on a production scale the fluidized-bed solidification of high-level liquid radioactive and aluminum nitrate wastes. Hot operation was begun in 1963 and continued until 1981. Over this time wastes other than the aluminum nitrate wastes have been processed. Major equipment components in the facility are the fluidized bed calciner, cyclone separator, quench tower, venturi scrubber, two deentrainment vessels, a heater and a set of four silica gel ruthenium adsorbers. The processing rate is approximately 2700 gallons of waste per day.

The New Waste Calcining Facility (NWCF) designed and constructed in the late 1970's and early 1980's replaces the WCF (Fo82). The NWCF was designed to meet more stringent requirements for safety, radiation exposure, effluent control, monitoring, and reliability. The WCF was maintained by contact methods but the NWCF was designed for remote maintenance. Major equipment items for the NWCF are the same as for the WCF, though improvements have been incorporated. The NWCF net processing rate is 3000 gallons of waste per day with a recycle rate of 15 percent. Thus, the NWCF flow rates are approximately 25 percent greater than WCF flow rates.

There are four solid waste storage facilities with storage volumes of 7800 ft^3, 30,000 ft^3, 39,000 ft^3, and 40,000 ft^3. Each facility consists of a number of steel structures in underground concrete vaults and each structure consists of two concentric bins around a central bin. There are annular air spaces for cooling between the bins.

B.1.2.8 The Tank Farms

The ICPP tank farm for storing high-level and intermediate activity wastes consists of fifteen underground stainless steel tanks -- nine with a 300,000 gallon capacity each, two 318,000 gallon tanks, and four 30,000 gallon tanks. The eleven largest tanks are in concrete vaults and the four small tanks rest on concrete pads.

Twelve of the tanks--eight of the large tanks and the four smaller tanks--are equipped with internal cooling systems. The cooling system for each of these consists of an internal cooling coil and a shell-and-tube reflux condenser. All tanks are vented through the process vessel off-gas system.

Approximately 2700 meters of stainless steel underground waste lines are in the tank farm.

B.1.3 Radiological Characterization

The greatest portion of wastes in the decontamination of a reprocessing plant are going to be contaminated equipment and structural materials such as concrete and steel. The contamination in any given area reflects the processes carried out in that area. Consequently, a characterization of process streams while the plant is operating qualitatively characterizes the D&D wastes in the different process areas.

The proccess streams at the ICPP can be considered to contain fission products (FP), plutonium or uranium. (Some HTGR fuel reprocessing streams contain thorium.) Representative process stream flow rates and radiochemical compositions for those streams enumerated in Figure B-1 are given in Table B-1.

From Table B-1 it can seen that fission product contamination of process equipment is expected in those areas involving fuel storage, dissolution, the first and second cycle extractions, high-level liquid waste

TABLE B-1

ICPP PROCESS STREAMS

Process Stream Number in Figure B-1	Stream	Flow Rate (l/hr)	U(g/l)	FP(Ci/l)	Pu(g/l)
1	1st extraction cycle feed	375	2.0	450	2×10^{-3}
2	High-level liquid waste	375	10^{-8}	450	10^{-2}
3	1st extraction cycle product	2.5*	300	2.6	0.34
4	2nd extraction cycle feed	5.25*	300	2.6	0.34
5	2nd extraction cycle liquid waste	30	3×10^{-6}	0.45	0.06
6	2nd cycle product	4.5	350	--	--
7	3rd cycle product	4.5	350	--	--
8	Intermediate activity liquid waste**	45	2×10^{-6}	0.30	0.04
9	Calciner Feed	10	10^{-8}	450	10^{-2}

---

* The difference in flow rates between 3 and 4 results from storage between cycles 1 and 2.

** This stream may be concentrated in an evaporator.

storage, calcination, intermediate activity liquid waste storage and solid waste storage. TRU contamination is also possible in all of these areas.

B.1.3.1 Assumptions

To arrive at total volume and curie estimates for the ICPP D&D wastes a number of assumptions had to be made. Some of these assumptions parallel those made in the Barnwell Fuel Reprocessing Plant (BNFR) D&D study (Sc77) and others are unique to the ICPP. Because the design data base on the ICPP is not as detailed as that on the BNFR, the ICPP volume estimates and the underlying assumptions are necessarily less accurate.

The major assumptions used in this study are described in the following paragraphs.

The ICPP has operated for nearly 30 years and will continue to operate in the foreseeable future. The fuels processed and the wastes produced have and will vary in time. As a result, detailed chemical and radiological characterization is difficult. In this study we have assumed the predominant contaminants are fission products, with Cs-137 and Sr-90 prevalent. Fission product contamination of process equipment is expected to be most extensive in the dissolution, 1st extraction cycle, and high-level liquid waste (HLLW) areas. Typical HLLW concentrations are given in Table B-2. The composition of other high-level liquid wastes are expected to be similar. Some uranium contamination in the form of uranyl nitrate could exist in areas where concentrated solutions are handled. Spent high enrichment fuel does contain small amounts of plutonium and this may constitute a significant contaminant in some areas of the plant.

TABLE B-2

TYPICAL RADIOCHEMICAL COMPOSITION OF TANK FARM INVENTORY AS OF SEPTEMBER 26, 1973

(Ci/m^3)

Source: ERDA77

TABLE B-2

TYPICAL RADIOCHEMICAL COMPOSITION OF TANK FARM INVENTORY AS OF SEPTEMBER 26, 1973

(Ci/m^3)

Source: ERDA77

	First Cycle Raffinate			
Component	Aluminum-Zirconium Blend[a]	Aluminum-Electrolytic Blend[b]	Stainless Steel Sulfate[c]	Second and Third Cycle Raffinate
Cobalt-60	1.3	0.51	--	0.01
Zirconium-95	4.87	--	0	0.10
Niobium-95	6.38	--	--	0.0465
Ruthenium-106	76	31	0.222	4.02
Antimony-125	26.9	--	--	1.30
Cesium-134	178	16.9	67.5	0.695
Cesium-137	833	550	1.32×10^{4}	100
Cerium-144	710	202	0.460	1.19
Europium-154	13.0	495	--	0.330
Strontium-90	476	522	1.22×10^{4}	90.7
Tritium	0.368	21	--	0.065
Neptunium (total g/l)	3.36×10^{-10}	--	--	--
Uranium (total g/l)	3.78×10^{-8}	3.4×10^{-8}	--	2.10×10^{-6}
Plutonium (total g/l)	4.19×10^{-8}	7.3×10^{-9}	--	3.7×10^{-8}
Gross beta	4840	--	--	340

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[a] From the coprocessing of aluminum alloyed and zirconium alloyed fuel.
[b] From the processing of electrolytically dissolved aluminum alloyed fuel.
[c] From the processing of stainless steel alloyed fuel.

The estimates in this study assume immediate dismantling of the ICPP at the end of its operational period. No allowance is made for nuclide decay. It is likely, however, that there will exist areas within the facility that are out of service for a number of years before final shutdown. In these cases neglecting decay is a conservative assumption.

It is assumed that during the operational phase good housekeeping practices were used, no process equipment is recycled (all becomes waste), and all process wastes are removed from the site prior to D&D.

All process cells are assumed to be built from concrete with a steel floor pan extending 1 foot up each wall. The cell dimensions are assumed to be 5m x 6m x7m except for the Cells G and H, which are assumed to be 5m x 6m x 14m. The steel liner is considered waste and 5 inches of concrete are assumed to be removed from the cell surfaces as part of the D&D process.

The D&D of each 300,000 gal HLLW tank and its auxillary structures is assumed to give 350 m^3 of waste. The small HLLW tanks each contribute 100 m^3 of waste. Each ILLW tank is assumed to yield 100 m^3 of waste.

Process cells with dissolvers are assumed to be contaminated with the high-activity dissolver product (450 Ci/l). The amount of contamination is assumed to be about 1 percent of the dissolver acid charge volume. Ninety percent of this contamination is in the dissolver and 10 percent is on the cell walls. The dissolver contamination can be reduced by a factor of 1000 by chemical decontamination methods, i.e., the dissolver decontamination factor (DF) is 1000. The cell surface DF is assumed to be 2. (The steel liner covers only 15 percent of the surface and no distinction is made between the liner and concrete.)

Extraction, solvent recovery, and product cells are assumed to be contaminated with 0.2 percent of the hourly flow of the hottest stream in the cell. If this is less than one liter, a value of one liter is assumed.

The emptied HLLW tanks are coated with a 0.01 mm deep residue of HLLW (450 Ci/l). The surface area of each of the large tanks is assumed to be 700 m^2 plus an additional 700 m^2 for the cooling coils. Irregularities in the surfaces increase this contaminated area by a factor of 2. The tank DF is 10. Using these assumptions, after decontamination each HLLW tank contains approximately 1260 Ci. A small HLLW tank contains 1/10 this amount. The residual contamination of a low-activity liquid waste tank is assumed to be 1/2000 that of a large HLLW tank.

The decontaminated Waste Calcining Facility and New Waste Calcining Facility contain 2500 Ci and 2800 Ci, respectively.

B.1.3.2 Estimates of Waste Volumes and Activities

Using the assumptions in the preceding section, volume and concentration estimates for immediate dismantlement D&D wastes for the ICPP have been made. These estimates are given in Table B-3. The values given in Table B-3 entail a degree of uncertainty but are consistent with estimates generated for the Barnwell Facility (Sc77).

The most prominent feature of the ICPP estimates is the large contribution to the total waste volume and the total number of curies from the Tank Farm and the Solids Storage Facility. Wastes from the Tank Farm and the Solids Storage Facility comprise 37 percent and 18 percent, respectively, of

TABLE B-3

ESTIMATED DISMANTLEMENT D&D WASTES FOR ICPP

Facility	Volume (m^3)*	Specific Activity (Ci/m^3)	Major Contaminants
Fuel Receiving and storage including Peach Bottom	500	0.2	FP**
Main Process Building			
B cell	100	3.3	FP, U, Th
D cell	150	2.2	FP, U, Th
E cell	150	15.	FP, U
G cell	300	8.5	FP, U
Remaining cells and denitration room in laboratory building	1000	0.1	FP, U
Total	1700	3	
Pilot Plant			
HTGR headend cells (1&2)	300	6.7	FP, U, Th
Off-gas treatment (HTGR) cell	10	0.1	FP
Denitration (HTGR) cell			
Electrolytic dissolution cell	150	6.7	FP, U
Total	460	6.7	
Waste Treatment Building	100	0.5	FP
Waste Calcining Facility	350	7	FP, U, TRU
New Waste Calcining Facility	400	7	FP, U, Th, TRU
Tank Farm			
High Level Liquid Waste Tanks (12)	3000	3.0	FP, U, TRU
Intermediate-Activity Liquid Waste (3)	300	0.1	
Solids Storage Facility including pneumatic transport system	1500	0.1	FP, U, TRU
Solidified Decontamination Solutions and Solid Trash	700	0.1	
TOTAL (no volume reduction)	9010	***	

---

* No volume reduction

** The major FP's are Sr-90 and Cs-137 with smaller quantities of Ru-106, Sb-125, Cs-134, Eu-154 and Ce-144.

*** The total number of curies is approximately 23,000.

the total waste volume and the Tank Farm waste contains better than 40 percent of the total activity in the ICPP D&D waste.

B.2 SAVANNAH RIVER PLANT

The Savannah River Plant (SRP), near Aiken, S.C., has been producing tritium and special nuclear materials, primarily plutonium, for defense purposes since 1953. In addition, irradiated high enrichment fuels are processed to recover the uranium. All of these processes are carried out in the Chemical Separations Area (200 area).

B.2.1 Reprocessing at SRP

B.2.1.1 The Plutonium Process

The recovery of plutonium from irradiated uranium is accomplished using the Purex process (ERDA77a, AEC74) in the 200F area. This process is in wide use and is well documented (Be81, Lo67). The Purex process is a solvent extraction process and much of the equipment used is the same as the equipment used in the ICPP dual solvent process described above. The SRP Purex flowsheet is given in Figure B-3.

The headend processes are decladding and dissolution. In the decladding process the aluminum cladding surrounding the uranium metal is dissolved with a sodium hydroxide-sodium nitrate solution. The decladding solution is directed to intermediate activity waste treatment. The plutonium-containing uranium metal is then dissolved in hot nitric acid. The dissolver solution is clarified using a manganese oxide precipitate.

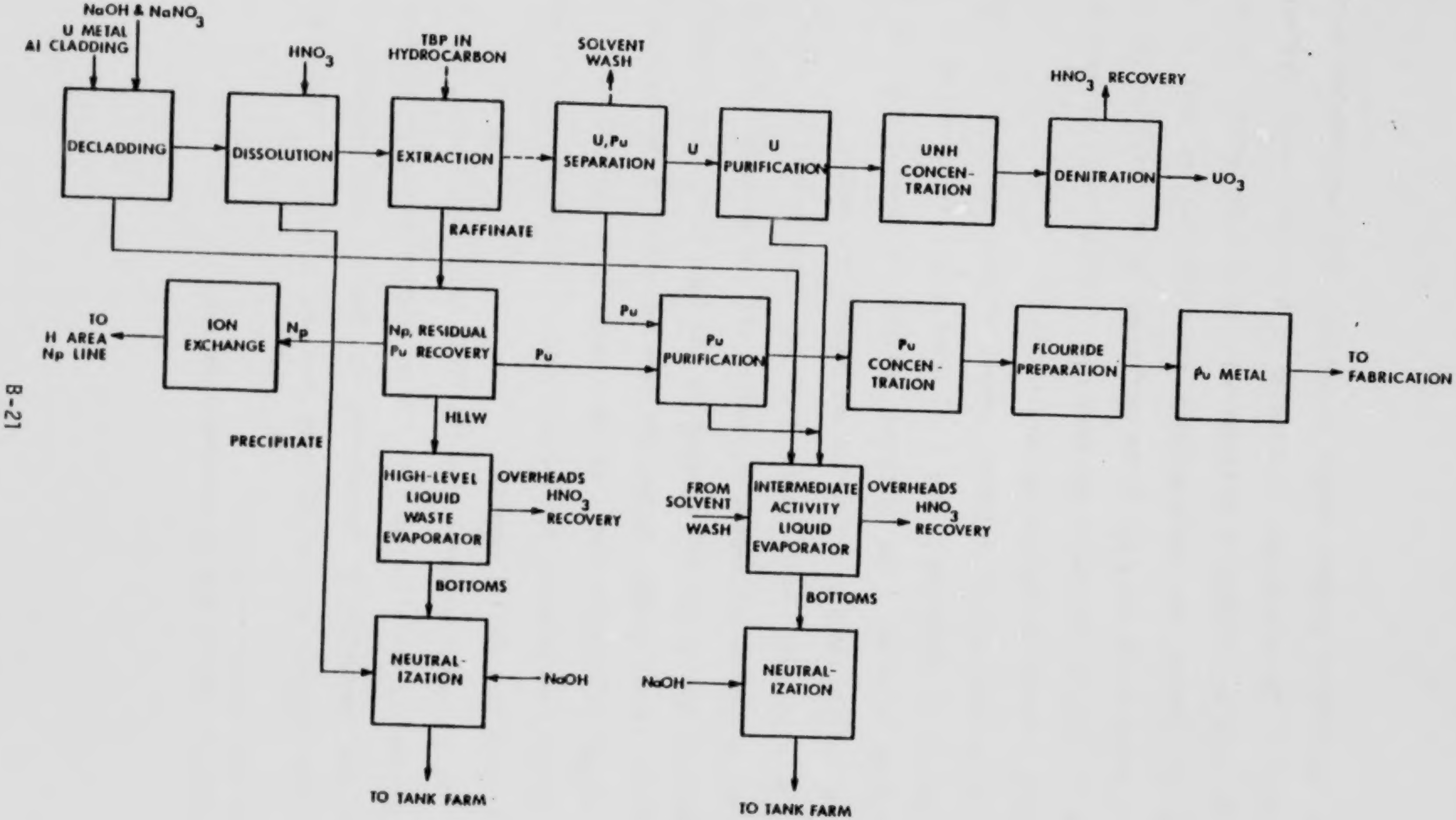
NaOH & NaNO$_3$
U METAL
Al CLADDING
DECLADDING
HNO_3
DISSOLUTION
TBP IN HYDROCARBON
EXTRACTION
SOLVENT WASH
U,Pu SEPARATION
U
U PURIFICATION
UNH CONCENTRATION
HNO_3 RECOVERY
DENITRATION
UO_3
RAFFINATE
TO H AREA Np LINE
ION EXCHANGE
Np
Np, RESIDUAL Pu RECOVERY
Pu
Pu
Pu PURIFICATION
Pu CONCENTRATION
FLOURIDE PREPARATION
Pu METAL
TO FABRICATION
HLLW
PRECIPITATE
HIGH-LEVEL LIQUID WASTE EVAPORATOR
OVERHEADS HNO_3 RECOVERY
FROM SOLVENT WASH
INTERMEDIATE ACTIVITY LIQUID EVAPORATOR
OVERHEADS HNO_3 RECOVERY
BOTTOMS
BOTTOMS
NEUTRALIZATION
NaOH
NaOH
NEUTRALIZATION
TO TANK FARM
TO TANK FARM

FIGURE B-3. SAVANNAH RIVER PLANT PUREX FLOWSHEET (200F AREA)

Though most fission products remain in solution, some are adsorbed on the precipitate. The precipitate is directed to high-level waste treatment.

The dissolver product is contacted with TBP in hydrocarbon. The plutonium and uranium are preferentially extracted, leaving most of the fission products and neptunium in the raffinate. In the next step the plutonium is reduced chemically and separated from the uranium; each then undergoes a second extraction for purification.

The uranium product solution, uranyl nitrate (UNH), is then concentrated in an evaporator. The final uranium step is conversion of UNH to uranium trioxide. The plutonium solution is concentrated via ion exchange, precipitated as a flouride and reduced to a metal.

The high-level liquid waste from the first extraction cycle has residual plutonium and neptunium removed via ion exchange before being evaporated, neutralized and directed to the tank farm. The neutralized waste will form a sludge. At the tank farm the supernate is separated from the sludge and concentrated. As the concentrated supernate cools salts precipitate from solution, forming salt cake. Intermediate-activity wastes are treated in a similar manner.

The plutonium recovered from the first cycle high-level liquid waste is directed to the plutonium line. After passing through an ion exchange step the neptunium is transferred to the H area neptunium line.

The capacity of the plutonium recovery process is 3000 MTHM/yr.*

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* MTHM/yr: Metric tons of heavy metal per year.

B.2.1.2 The Uranium and Neptunium Process

The SRP high enriched uranium recovery process in the 200 H area is also a solvent extraction process and is similar to the Purex process. In addition to uranium, some neptunium is recovered in this process. The fuel reprocessed is SRP reactor fuel. Figure B-4 shows the process flowsheet. Approximately 15 MTHM can be processed in a year.

Also in the 200 H area plutonium 238 is recovered from irradiated neptunium targets. The plutonium and neptunium products of this process are transferred to a finishing area where they are first precipitated as oxalates and then calcined to oxides. The PuO_2 is packaged for shipment off site and the NpO_2 is transferred to a metallurgical facility where it is eventually refabricated into target elements.

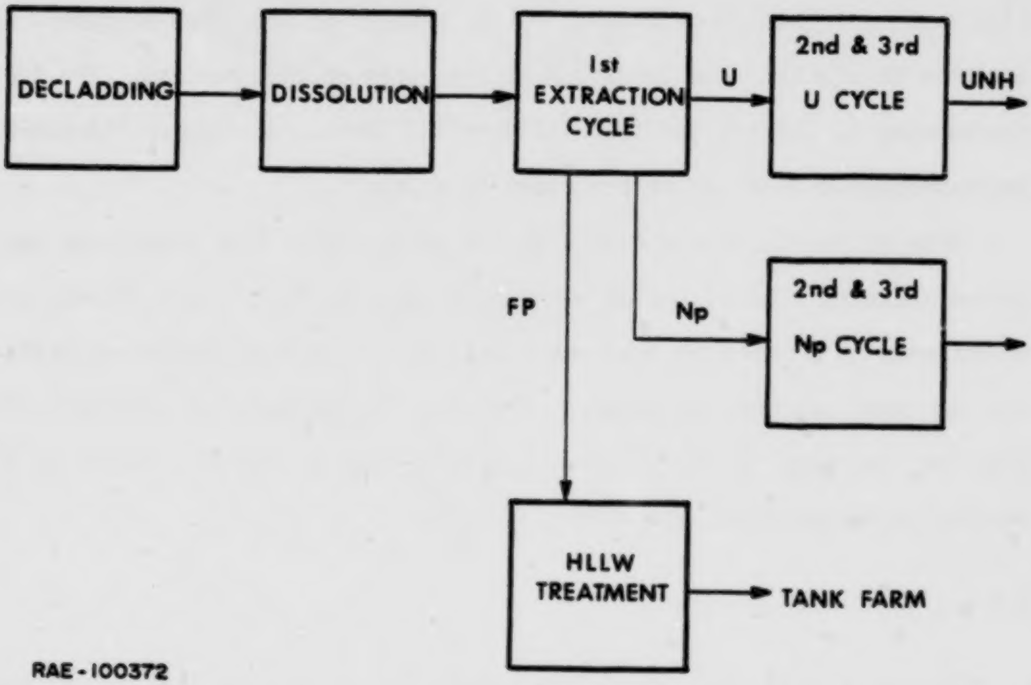
B.2.1.3 The Tritium Process

Another H area activity is the separation of tritium from irradiated Li-Al targets. The targets are heated in a furnace and the gases, including hydrogen and helium isotopes, are extracted under vacuum. The solid wastes are packaged and sent to a burial ground.

B.2.2 SRP Reprocessing Facilities (200 Area)

B.2.2.1 F Area

The Purex process at SRP is located in the 221-F canyon (approximately 240m x 36m). Other buildings in this area involved with reprocessing include a low activity contaminated water and chemical handling facility, a


DECLADDING
DISSOLUTION
1st EXTRACTION CYCLE
U
2nd & 3rd U CYCLE
UNH
FP
Np
2nd & 3rd Np CYCLE
HLLW TREATMENT
TANK FARM

RAE-100372

FIGURE B-4. SAVANNAH RIVER PLANT URANIUM RECOVERY (H AREA) waste concentration system, the main analytical laboratory and the plutonium metallurgical facility. Other structures include the canyon ventilation sand filters, 30m x 72m x 2.4m and 30m x 90m x 2.4m, and 14 million gallon seepage basin. The total tankage of the F and H area tank farms is assumed to be about 53 million gallons in 47 tanks. This is based on existing and proposed tankage in 1977 (ERDA77a).

B.2.2.2 H Area

The 221-H Canyon (240m x 36m) contains the high enrichment uranium reprocessing and neptunium lines. Other associated structures include a low activity contaminated water and chemical handling system, a waste concentration system, the tritium separation facilities, a receiving basin for off-site fuels, sand filters and seepage basins.

B.2.3 SRP Reprocessing Facilities D&D Wastes

Estimates for the SRP decontamination and decommissioning volumes are based on building areas using the ICPP estimates and BNFP estimates (Sc77) for guidance. The estimates are given in Table B-4. Specific assumptions are footnoted in the table.

B.3 HANFORD

Since the mid-1940's the 200 area facilities at Hanford have been producing plutonium for defense purposes (ERDA 75). Currently no reprocessing activities are being undertaken; the 200 East Purex plant is being held on standby. Throughout the history of the Hanford site a number of

TABLE B-4

SAVANNAH RIVER PLANT REPROCESSING FACILITIES D&D WASTES

Facility	Volume (m^3)	Specific Activity[g] (Ci/m^3)	Nuclides
221 F (Purex) and support facilities	8700[a]	7	FP, U, Pu, Np
221 H (U, Np) and support facilities	8700[a]	1-5	FP, U, Np
232 F, 234 F, 238 F (Tritium)	500[b]	unknown	^3H
Receiving Basin	500[c]	0.1	FP
Sand Filters	5000[d]	0.1	FP
Seepage Basins	200,000[e]	0.1	FP, U, Pu, Np
F and H Tank Farms	30,000[f]	1-5	FP, U, Pu, Np
Solidified decontamination liquids and trash	1,500		
TOTAL	254,900		
TOTAL less seepage basin	54,900		

---

[a] Area x 1m.
[b] Area x 0.1m.
[c] Assumed volume based on BNFP.
[d] 5 inches concrete from surfaces, plus sand.
[e] Contamination to 2 meters
[f] $100m^3$ for each 100,000 gallons (HLW tanks)
$30m^3$ for each 100,000 gallons (LLW tanks)
[g] Concentration based on ICPP and BNFP estimates.

plants have been operated and these are now idle. It is possible that some of them will be modified for other uses in the future.

B.3.1 Reprocessing at Hanford

Several processes have been used at Hanford since the beginning of operations. Initially plutonium was recovered using the Bismuth Phosphate process (Lo67). This process, which produced large amounts of waste and from which the uranium was not recovered, was abandoned in favor of the Redox process (Lo67). The Redox process, which also produces large amounts of waste, was replaced with the Purex process in the 1950's. The Purex process capacity is 1000 MTHM/yr.

B.3.2 Reprocessing Facilities at Hanford

The Hanford 200 area is divided into the 200 East and 200 West areas. Facilities in the 200 East area include the Purex plant, the B plant, the Semiworks Critical Mass Laboratory, and eight tank farms (A, AX, AY, AZ, B, BX, BY, C). Until recently plutonium, uranium and neptunium were recovered using a backcycle Purex process (ERDA75, Lo67) in the Purex plant. Support processes include solvent recovery, nitric acid recovery, and waste concentration and treatment. The B plant was built in the 1940's for the Bismuth Phosphate process but later converted to a waste fractionation plant where Cs-137 and Sr-90 were removed from high-level liquid wastes and self-boiling sludges. The cesium and strontium were converted to the chlorides and fluorides, respectively, and doubly encapsulated. The Semiworks and Critical Mass Laboratory has been used as a Redox pilot plant, a Purex pilot plant, a processing and loadout area for fission products (involving millions of curies of Sr-90, Pm-147, and Ce-144) and a waste fractionation pilot plant.

The 200 West facilities include the U plant, the Redox plant, the Z plant, the T plant, and 6 tank farms (S, SX, T, TX, TY, U). The U plant was designed for the Bismuth Phosphate process but was never used in that capacity. At the startup of the Redox process the U plant was used for the recovery of U from stored wastes (1952-58). An adjacent UO_2 plant, however, was used to convert the Purex UNH solutions to UO_3. The Redox process was run in the Redox plant which is now shut down. The T plant was designed, built and operated for the Bismuth Phosphate process. It ran until 1956. Since then its floor space has been used on an irregular basis for decontamination projects and equipment repair. Part of the plant has been used for plutonium nitrate solution storage. The Z plant is the site of the plutonium laboratory and finishing operations. Activities have included conversion of plutonium nitrate to the oxide or metal and recovery of scrap plutonium.

The total tankage in the 200 areas is assumed to be about 75 million gallons. In addition to high level-liquid waste the tank farms, some intermediate-activity liquid wastes were percolated into the ground through more than 150 cribs and french drains. Nonradioactive and low-activity wastes were directed to ponds for evaporation or percolation. More than 5 million ft^3 of solid waste have been buried.

B.3.3 Estimates of Hanford D&D Wastes

Estimates for Hanford 200 area decontamination and decommisioning wastes are based on building areas using the ICPP estimates and BNFP estimates (Sc77) for guidance. The estimates are given in Table B-5. Specific assumptions are footnoted in the table.

TABLE B-5

HANFORD 200 AREA D&D WASTES

Facility	Volume (m^3)	Specific Activity[e] (Ci/m^3)	Nuclides
Purex Plant	12,000[a]	<1	FP, U, Pu, Np
B Plant & Semiworks	7,200[a]	>1	FP
U Plant	7,700[a]	>1	FP, U, Np
Redox Plant	4,500[a]	<1	FP, U, Pu, Np
Z Plant	8,800[a]	<1	Pu
T Plant	7,200[a]	<1	FP, U, Pu
Tank Farms	50,000[b]	1 to 5	FP, U, Pu, Np
Cribs	10^7 [c]	<<1	FP, U, Pu, Np
Solids Buried	135,000[d]	unknown	unknown
Solidified decontamination liquids and trash	2,000		
Total	1.02×10^7		
TOTAL less cribs and solids buried	97,400		

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[a] Area x 7m.
[b] $66 m^3$ per 100,000 gallons tankage
[c] FB80.
[d] ERDA 75.
[e] Concentration based on ICPP and BNFP estimates.

APPENDIX C

FEDERALLY CONTROLLED ACCELERATORS
(ACTIVE)

References For Tables	Reference
A	Op79
B	Ep81
C	ERC82
D	DOE79c
E	DOE81c

TABLE C-1

LINEAR ACCELERATORS

Facility and Location	Proton Energy (MeV)	Initial Operation	Number of Accelerators	Agency	Reference
Argonne National Laboratory Argonne, Illinois Electron Linacs	22	1969	1	DOE	B, C
Bates Massachusetts Institute of Technology Cambridge, Massachusetts	400	1972	1	DOE	B, C
Battelle Pacific Northwest Laboratory 1 Battelle Boulevard Richland, Washington			5	DOE	C
Brookhaven National Laboratory Upton, New York			1	DOE	A, D
Center for Energy and Env. Research Mayaquez, Puerto Rico	0.22		1	DOE	E
Fermi National Accelerator Laboratory Batavia, Illinois Linac to Main Accelerator	200	1977	1	DOE	B, C
Franklin McLean Res. Hosp. FNMRI University of Chicago Chicago, Illinois	50		1	DOE	B, C, D
Lawrence Berkeley Lab Berkeley, California Super Hilac		1971	1	DOE	A, B, C
Lawrence Livermore National Lab. Livermore, California	100	1959	1	DOE	A, B, C
	35	1970	1	DOE	A, B, C
			2	DOE	A, B, C
Los Alamos National Laboratory Los Alamos Meson Physics Facility Los Alamos, New Mexico LAMPF	800	1972	1	DOE	A, B, C
National Bureau of Standards Washington, D.C.	150	1966	1	DOC	C

TABLE C-1 (CONT)

LINEAR ACCELERATORS

Facility and Location	Proton Energy (MeV)	Initial Operation	Number of Accelerators	Agency	Reference
Oak Ridge National Laboratory					
Building 6010					
Oak Ridge, Tennessee					
Electron Linear Accelerator	140	1969	1	DOE	C
Rensselear Polytechnic Inst.					
Rensselear, New York					
Proton Linac	100	1961	1	DOE	B, C
Electron Linac	100		1	DOE	B, C
Sandia Corp.					
Albuquerque, New Mexico					
Linac			1	DOE	D
Stanford University					
Stanford, California					
Stanford Liner Accelerator	22,000	1966	1	DOE	A, B, C
Spear	25,000	1972	1	DOE	B, C
Mark III	2,000	1972	1	ONR/NSF	C
Linac	35		1		C
U.S. Air Force	15		1	DOD	C
Hill Air Force Base	10		1	DOD	C
Ogden, Utah	23		1	DOD	C
U.S. Army Ionizing Radiation Cen.			1	DOD	A, C
Lathrop, California					
U.S. Army Quartermaster Corps					
Natick, Massachusetts					
Lineac	10		1	DOD	A, C
U.S. Naval Postgraduate School					
Monterey, California					
Lineac	100	1965	1	DOD	C
U.S. Naval Research Lab					
Washington, D.C.					
Lineac	65	1964	1	DOD	C
Veterans Administration Hospital					
East 54th St. & 48th Ave., South					
Minneapolis, Minnesota 55417					
Lineac	4		1	DOD	C

TABLE C-2

CYCLOTRONS

Facility and Location	Proton Energy (MeV)	Initial Operation	Number of Accelerators	Agency	Reference
Argonne National Laboratory Argonne, Illinois 60-Inch Cyclotron	23	1952	1	DOE	A, B, C
Midwest Tandem Cyclotron			1	DOE	A, C
Brookhaven National Laboratory Upton, New York Brookhaven Cyclotron 60" AVF	36	1968	1	DOE	A, B, C
University of Colorado Boulder, Colorado 52-Inch AVF	50	1962	1	DOE	B, C
Duke University Durham, North Carolina 31-Inch AVF	15	1968	1	DOE	B, C
Franklin McLean Mem. R. Institute Chicago, Illinois University of Chicago	16		1	DOE	B, D
Laboratory of Nuclear Medicine and Radiation Bio. UCLA Health Sciences Building Cyclotron			1	DOE	E
Lawrence Berkeley Laboratory Berkeley, California Omnitron 88-Inch AVF	60	1962	1	DOE	A, B, C
Lawrence Livermore National Laboratory Berkeley, California 20-Inch AVF Neg. Hydrogen Ion	15	1969	1	DOE	A, B, C

TABLE C-2 (CONT)

CYCLOTRONS

Facility and Location	Proton Energy (MeV)	Initial Operation	Number of Accelerators	Agency	Reference
Los Alamos Scientific Laboratory Los Alamos, New Mexico			1	DOE	A
Maryland, University of College Park, Maryland 105-Inch AVF	140	1969	1	DOE	B, C
NASA-Lewis Research Center 21000 Brookpark Road Cleveland, Ohio 60-Inch FF	21	1952	1	NASA	A, B
Oak Ridge National Laboratory Oak Ridge, Tennessee		1975	1	DOE	A, B, C
Hollifield Heavy Ion Research Facility 76 Inch AVF Isochronous Cyclotron	3		1	DOD	A
Accelerator for Physics and Chemistry of Heavy Elements	66	1964	1	DOE	A, C
		1975	1		A
Sloan-Kettering Institute New York, New York Cyclotron (Cs-15)	20	1967	1	DOE	B, C
Texas A and M Texas	60	1967	1	DOE	B, C
U.S. Naval Research Laboratory Washington, D.C. Isochronous Cyclotron 76-Inch AVF	50	1967	1	DOD	A, B, C

TABLE C-3

SYNCHROTRONS

Facility and Location	Proton Energy (MeV)	Initial Operation	Agency	Reference
Ames Laboratory Iowa State University (has been decommissioned)	70	1949	DOE	B
Argonne National Laboratory Argonne, Illinois				
Intense Pulsed Neutron Source	500	1976	DOE	B
ZGS Booster Synchrotron I	200			C
Brookhaven National Laboratory Upton, New York				
30 Ft. Synchrotron			DOE	A, C
Alternating Gradient Synchrotron	33,000	1960	DOE	A, B, C
Fermi National Accelerator Lab Weston, Illinois	500,000 Being increased to 1,000,000		DOE	B
U.S. Naval Research Laboratory Washington, D.C.			DOD	A, C

TABLE C-4

DIRECT CURRENT MACHINES

Facility and Locations	Proton Energy (MeV)	Initial Operation	Number and Type of Accelerator	Agency	Reference
Aerospace Res. Lab	2				A, C
Argonne National Laboratory					
Argonne, Illinois	2		V. de Graaff	DOE	A, B, C
	3		V. de Graaff	DOE	A, B, C
Zero Gradient Injector	4	1969	1-Dynamitron	DOE	B, C
	50	1963	1-Cockroft-Walton	DOE	A, B, C
Bettis Atomic Power Laboratory			3-V. de Graaff	DOE	A, C
Pittsburg, Pennsylvania					
Brookhaven National Laboratory	4	1954	2-V. de Graaff	DOE	A, B, C
Upton, New York	2		2-V. de Graaff	DOE	A, B, C
	2		1-Dynamitron	DOE	B, C
Duke University					
Durham, North Carolina	3.3	1961	1-V. de Graaff	DOE	B
	4.0	1952	1-V. de Graaff	DOE	B, C
Franklin McLean Res. Hosp.					
University of Chicago	2		1-V. de Graaff	DOE	B, C, D
Chicago, Illinois					
General Electric Co.					
Hanford Lab	2		2-V. de Graaff	DOE	C
Richland, Washington					
Lawrence Berkeley Laboratory	0.5		2-Cockroft-Walton	DOE	C
Berkeley, California	4		1-V. de Graaff	DOE	C
	0.48	1962	1-Cockroft-Walton	DOE	A, C
	0.75		2-Cockroft-Walton	DOE	C
Lawrence Livermore National Lab.	1		1-V. de Graaff	DOE	C
Livermore, California	0.5		1-Cockroft-Walton	DOE	C

TABLE C-4 (CONT)

DIRECT CURRENT MACHINES

Facility and Locations	Proton Energy (MeV)	Initial Operation	Number and Type of Accelerator	Agency	Reference
Los Alamos National Laboratory Los Alamos, New Mexico	0.50		1-Cockroft-Walton	DOE	A, C
	0.25		1-Cockroft-Walton	DOE	A, B, C
	9		1-V. de Graaff	DOE	A, B, C
	3		1-V. de Graaff	DOE	A, B, C
National Bureau of Standards Washington, D.C.			1-A-C-Rectifier	DOC	A, C
	0.25		1-Cockroft-Walton	DOC	A, C
	2	1955	1-V. de Graaff	DOC	A, C
National Institutes of Health Public Health Service Bethesda, Maryland	2		2-V. de Graaff	DHHS	A, C
	3		1-V. de Graaff	DHHS	C
University of Notre Dame South Bend, Indiana	2		1-V. de Graaff	DOE	B, C
	4	1956	1-V. de Graaff	DOE	C
Oak Ridge National Laboratory Oak Ridge, Tennessee			1-Cockroft-Walton	DOE	A
	0.25		1-Cascade	DOE	A,C
	6	1950	1-V. de Graaff	DOE	A, B, C
	3	1948	1-V. de Graaff	DOE	A, B, C
			1-V. de Graaff	DOE	A, B, C
Redstone Arsenal Huntsville, Alabama	2		1-V. de Graaff	DOD	C
Renesselear Polytechnic Institute Troy, New York	0.25		1-Cockroft-Walton		
	1		1-V. de Graaff		C
Sandia Corp. Albuquerque, New Mexico	2		1-V. de Graaff	DOE	A, C, D
			1-Cockroft-Walton	DOE	A, C, D
U.S. Air Force, Air Material Command Wright-Patterson AFB, Ohio	2	1953	1-V. de Graaff	DOD	A, C

TABLE C-4 (CONT)

DIRECT CURRENT MACHINES

Facility and Locations	Proton Energy (MeV)	Initial Operation	Number and Type of Accelerator	Agency	Reference
U.S. Army Chemical Center Chemical & Radiological Lab. Army Chemical Center, Maryland	0.3		1-V. de Graaff	DOD	A, C
U.S. Army Quartermaster Corps Natick, Massachusetts	1		1-V. de Graaff	DOD	A
U.S. Naval Hospital Bethesda, Maryland	2		1-V. de Graaff	DOD	A, C
U.S. Naval Postgraduate School Monterey, California	2		1-V. de Graaff	DOD	A, C
U.S. Naval Research Laboratory Washington, D.C.	0.5		1-Cockroft-Walton	DOD	A, B, C
	0.25		1-Cockroft-Walton	DOD	A, B, C
	2.1		1-V. de Graaff	DOE	A, C
	2.0		1-V. de Graaff	DOE	A, C
	6.0		1-V. de Graaff	DOE	A, C
	5.5		1-V. de Graaff	DOE	A, C

TABLE C-5

BETATRONS

Facility and Location	Proton Energy (MeV)	Agency	Reference
Detroit Arsenal Ordnance Corps Center Line, Missouri	15	DOD	A, C
Picatinny Arsenal Dover, New Jersey	24	DOD	A, C
U.S. Naval Ordnance Laboratory Silver Springs, Maryland	10	DOD	A, C
U.S. Naval Research Laboratory Washington, D.C.	21	DOD	A, C
U.S. Navy Electronics Laboratory San Diego, California	26	DOD	A, C
Watervliet Arsenal Watervliet, New York	24	DOD	A, C

TABLE C-6

TANDEM ACCELERATORS

Facility and Location	Proton Energy (MeV)	Initial Operation	Number of Accelerators	Agency	Reference
Aerospace Res. Lab Tandem Van de Graaff (T-8)	8	1967	1		B, C
Argonne National Laboratory 9700 South Cass Avenue Argonne, Illinois Tandem Van de Graaff Facility	18	1967	1	DOE	A, B, C
Tandem Dynamitron			1	DOE	A, C
Army Nuclear Eff. Lab. Edgewood Arsenal, Maryland Tandem Van de Graaff (FN)	15	1969	1	USA	B, C
Brookhaven National Laboratory Building 901A Upton, New York Tandem Van de Graaff Facility	30	1970	1	DOE	A, B, C
University of California Lawrence Livermore National Laboratory Livermore, California Cyclograaff Laboratory L-330	27	1971	1	DOE	A, B, C
Duke University Durham, North Carolina 3-Stg Tandem Van de Graaff	32	1968	1	DOE	A, B
Kansas State University Manhattan, Kansas Tandem Van de Graaff	12	1969	1	DOE	B, C
Los Alamos National Laboratory Los Alamos, New Mexico Los Alamos Tandem Accelerator Fac.	24.5	1964	1	DOE	A, B, C
University of Minnesota Minneapolis, Minnesota Williams Laboratory of Nuclear Physics Tandem Van de Graaff	20	1966		DOE	B, C
Oak Ridge National Laboratory Building 5500 Oak Ridge, Tennessee Van de Graaff Laboratory	13	1962	1	DOE	A, B, C
Oak Ridge Heavy Isotope Lab.			1		A

TABLE C-6 (CONT)

TANDEM ACCELERATORS

Facility and Location	Proton Energy (MeV)	Initial Operation	Number of Accelerators	Agency	Reference
Ohio University John E. Edwards Accelerator Lab. Athens, Ohio Tandem Van de Graaff	11	1970	1	DOE	B, C
U.S. Army Ballistic Research Lab. Abderdeen Proving Ground, Maryland Radiation Laboratory (Moved to U of Pennsylvania in 1975)			1	DOD	A
Wisconsin, University of Madison Sterling Hall Madison, Wisconsin Tandem Van de Graaff	12	1960	1	DOE	B, C
Yale University Arthur William Wright Nuclear Structure Laboratory New Haven, Connecticut Tandem Van de Graaff	22	1966	1	DOE	B, C

TABLE C-7

OTHER ACCELERATORS

Facility and Location	Proton Energy (MeV)	Initial Operation	Agency	Reference
Argonne National Laboratory 9700 South Cass Avenue Argonne, Illinois				
Fast Neutron Generator		1970	DOE	A, C
Bettis Atomic Power Laboratory Pittsburg, Pennsylvania				
Neutron Generator			DOE	A, C
Fermi National Accelerator Lab. Weston, Illinois				
Synchrocyclotron	450		DOE	
Lawrence Berkeley Laboratory Berkeley, California				
184-Inch Synchrocyclotron	730	1946	DOE	A, B, C
Bevatron	6200	1954	DOE	A, B, C
Oak Ridge National Laboratory Oak Ridge, Tennessee				
Cascade	0.6		DOE	C

APPENDIX D

CHARACTERISTICS OF REACTOR ACTIVATION PRODUCTS

Source: Ko82

Hydrogen-3 - Tritium is produced in beryllium by a two-step neutron capture radioactive decay process:

$$\text{Be-9 } (n,\alpha) \text{ He-6} \xrightarrow{\beta} \text{Li-6 } (n,\alpha) \text{ H-3}$$

Tritium has a radioactive decay half life of about 12.4 years and decays by beta emission, with a maximum energy of 18.6 keV.

Carbon-14 - Carbon-14 is produced by two processes: 1) by multiple neutron capture in C-12 and C-13 and 2) by neutron capture-proton emission in N-14. The second reaction is the predominant one. Both carbon and nitrogen are present in trace quantities in stainless and carbon steels. Carbon-14 has a radioactive decay half life of about 5,750 years and decays by beta emission, with a maximum energy of 156 keV.

Iron-55 - Iron-55 is produced principally by thermal neutron capture in 5.8%-abundant Fe-54 in iron, a constituent in stainless steel and carbon steel. Iron-55 has a decay half-life of 2.7 years and decays by orbital electron capture (EC) by the nucleus to form Mn-55.

Each EC event is accompanied by the emission of either x-rays or Auger electrons associated with Mn-55 stabilization to the ground energy state, with energies less than 7 keV. As is typical with such emissions from nuclides in this atomic number range, 74% of the x-rays are not emitted, and Auger electrons of the same energy appear instead. These emissions do not contain the energy (i.e., 68 keV) required to penetrate the outer dead layers of skin and, thus, do not contribute to a skin dose.

Each EC decay event is accompanied by a continuous spectrum of gamma rays from the associated inner bremsstrahlung process. The maximum energy of this spectrum is 220 keV.

Nickel-59 - Nickel-59 is produced primarily by thermal neutron capture in 68.3%-abundant Ni-58 in nickel, a constituent in stainless steel. Nickel-59 has a decay half life of approximately 80,000 years and decays by the EC process to Co-59.

X-rays or Auger electrons are emitted during stabilization to the ground energy state. In the case of Co-59, the energies are less than 8 keV, and approximately 33% of the emissions are x-rays and the rest are Auger electrons. These emissions do not contribute to the external radiation dose rate.

The contribution of the Ni-59 decay process to external dose rate comes from the EC-associated inner bremsstrahlung process. A continuous spectrum of gamma rays is emitted, with a maximum energy being 1.07 MeV. The total incidence for gamma rays greater than 70 keV is about 10^{-3}.

Nickel-63 - Nickel-63 is produced by thermal neutron capture in 3.6%-abundant Ni-62 in nickel, a constituent in stainless steel. Nickel-63 has a decay half life of about 100 years and decays by beta emission to Cu-63. The beta emissions have maximum energies of about 66 keV, which is insufficient to penetrate the outer surface of the skin. No gamma rays are emitted. Therefore, Ni-63 does not contribute to the external dose rate.

Cobalt-60 - Cobalt-60 is produced by thermal neutron capture in 100%-abundant Co-59, a trace constituent in stainless steel, aluminum and beryllium. Cobalt-60 has a decay half life of 5.27 years and decays by beta emission to excited energy states of Ni-60. Over 99% of the decay events are to an excited energy state at 2.505 MeV, which goes to the ground energy state, with a sequential emission of two gamma rays of 1.173 MeV and 1.332 MeV. These are the major contributors to the dose rate from Co-60.

Zinc-65 - Zinc-65 is formed by neutron capture in 48.6%-abundant Zn-64, an element found in aluminum alloys. Neutron capture leads to Zn-65, which decays by beta emissions to the 1.115 MeV level of Cu-65 (49%) or by EC (49%) or beta emission (1.7%) to the ground state of Cu-65. A 1.115-MeV gamma ray is emitted when the excited level drops to the ground state. The maximum beta energy is about 0.3 MeV. The half life for radioactive decay of Zn-65 is 244 days.

Cadmium-113m - Cadmium-113m is formed by neutron capture in 24.1%-abundant Cd-112, a trace element found in beryllium. The excited state, Cd-113m, decays to the ground state by emitting a 0.265-MeV gamma ray, (0.1% of transitions) or decays to the ground state of In-113 by emitting a 0.58-MeV beta (99 + % of transitions). The radioactive decay half life is about 14.6 years.

Niobium-94 - Niobium-94 is formed by thermal neutron capture in 100%-abundant Nb-93, a trace constituent in stainless steel. Neutron capture leads either to the ground state of Nb-94 or to an isomeric state that is 41 keV above the ground state. The isomeric state decays with a half-life of 6.26 minutes. Most (99.5%) of these decays go to the ground energy state. Thus, for long-time radiation dose rate considerations, all neutron captures lead to the ground energy state. Niobium-94 has a decay half life of 20,300 years and decays by beta emission, with a maximum beta energy of 471 keV. All of the decays go to a single excited energy state of Mo-94 at 1.574 MeV excitation. All of the decays from this state go through an excited energy state at 871 keV. Thus, each Nb-94 decay yields two gamma rays with energies of 703 and 871 keV, respectively.

Niobium-92 - Niobium-92 has a long half life (3.6×10^7 years); however, it is not a fission product and the cross sections for production by neutron activation (e.g., Nb-93 n, 2n) are small. It decays by electron capture. There are two gammas (560 and 930 keV) with greater than 99% intensity (Ko81).

Zirconium-93 - Zirconium-93 is formed by neutron capture in Zr-92 and is also a fission product. Zirconium, composed of 17.11 percent Zr-92, 12.23 percent Zr-91, and 51.46 percent Zr-90, is used in power and Naval reactors. Alloys of it generally contain over 95 percent zirconium (Be81). Zirconium-93 has a decay half life of 1.5×10^6 years. It decays by beta emission (61 keV) to Nb-93m, which has a half life of 14.6 years and decays by isomeric transition to Nb-93. There are several x-rays (16 to 19 keV) associated with the decay of Nb-93m (Ko81).

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